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ABSTRACT

This report summarizes an analysis of options for connecting the nation's public K-12 schools to the national information infrastructure (NII)--or information superhighway. It incorporates insights drawn from visits to schools and interviews with educators, policymakers, and technology experts around the country, as well as from a review of the literature on the educational uses of technology and connectivity. The report begins with a summary of the principal applications and benefits of connecting public K-12 schools to the NII. Then, to illustrate the costs and highlight the challenges of capturing those benefits, a series of models is described for deploying the technology infrastructure, for putting into place the needed connections, hardware, content, and human resources. The next section identifies the three major challenges to successful deployment, funding, professional development for teachers, and courseware development, and outlines potential ways to avoid those hurdles. In conclusion, the report highlights some of the leadership challenges posed by technology deployment, underscoring that success will ultimately depend on the creativity and sustained commitment of leadership at school, district, community, state, and national levels. Appendices provide details for the costs models mentioned in the report, a description of models and cost estimates from other studies, and a breakdown of current technology spending in public K-12 schools. A glossary and list of interviews is included. (Contains 48 references.) (Author/AEF)

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CONNECTING K-12 SCHOOLS TO THE INFORMATION SUPERHIGHWAY

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CONNECTING K-12 SCHOOLS TO THE INFORMATION SUPERHIGHWAY

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PREFACE

This report was developed by McKinsey & Company, Inc. for the National Information Infrastructure Advisory Council (NIIAC). Many individuals from educational organizations, industry, and federal, state and local governments lent their expertise to this effort. While their contributions have been invaluable, the report does not necessarily reflect the views of any one contributor, the NIIAC, or its members. Comments and questions concerning this work should be directed to Michael Nevens, McKinsey and Company, Inc., 630 Hansen Way, Palo Alto, California 94304; or to Margot Singer, McKinsey and Company, Inc., 55 East 52nd Street, New York, New York 10022.

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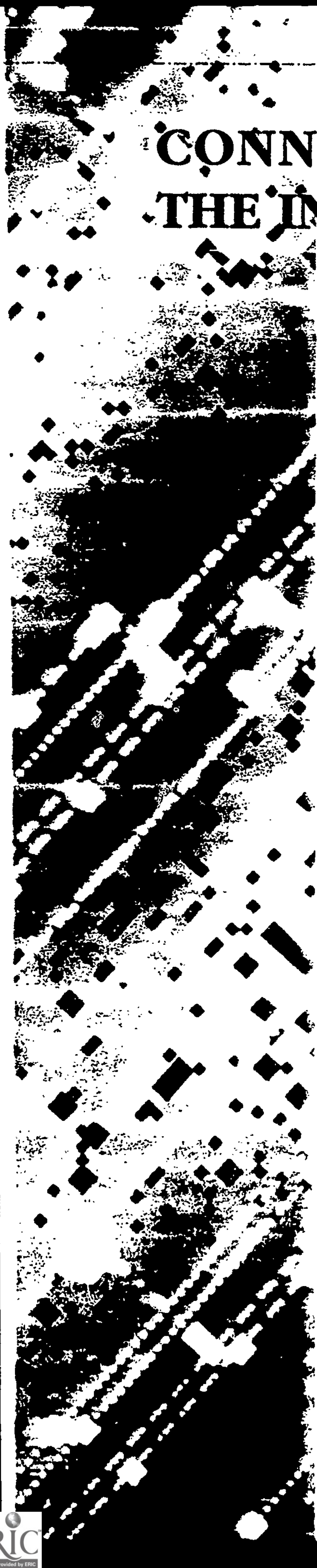
TABLE OF CONTENTS

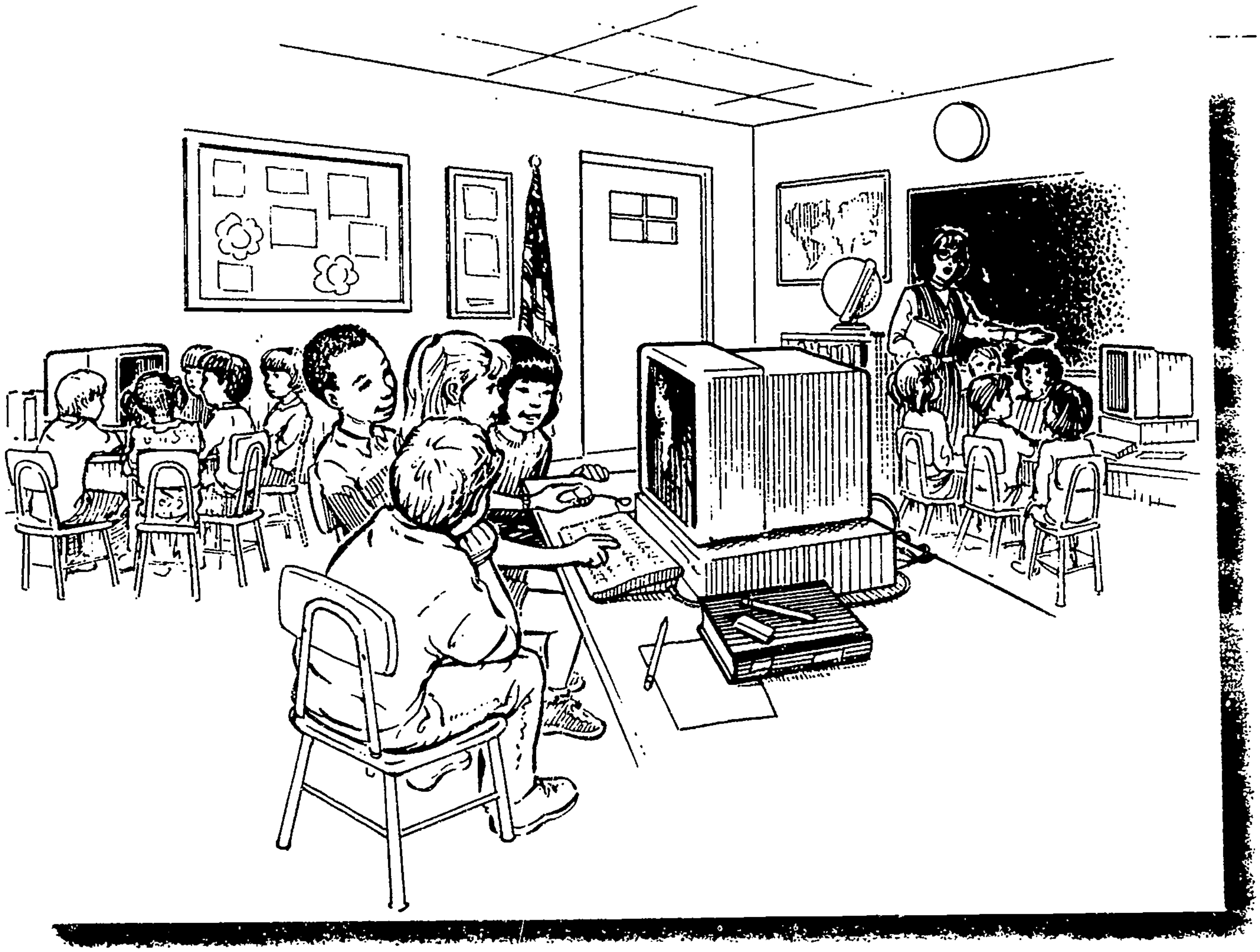


CONNECTING K-12 SCHOOLS TO THE INFORMATION SUPERHIGHWAY

EXECUTIVE SUMMARY

Connecting all of America's public K-12 schools to the national information infrastructure (NII) would be valuable and is achievable. The NII, frequently called the "information superhighway," offers services and resources that help students not only to master technical and vocational skills, but also to achieve significant improvements in academic performance. In addition, connection to the information superhighway provides teachers access to a broad array of on-line curricular materials and innovative instructional approaches. It also opens up new communication channels between students and teachers, teachers and their peers, and schools and their communities.

The technology for providing schools access to these resources and services exists today, and the costs of installing and supporting that technology would represent a small portion of the public education budget. Depending on how much technology is deployed and how quickly, the cost of connecting all public K-12 schools to the information superhighway—including not only the connection, hardware, and content costs, but also essential professional development and support for teachers—could range from 1.5% to 3.9% of the total K-12 budget nationwide during the peak year of expenditures. By comparison, 1.3% of the public K-12 budget is spent on similar technology today.



Each school and district will need to make choices about how much investment in technology is required to achieve its educational goals, and how fast it wishes to deploy the technology infrastructure. Across all schools, however, the pace of deployment and the capture of educational benefits will be strongly influenced by three factors: the availability of funding, professional development opportunities for teachers and other school professionals, and the pace of courseware development. While installing the hardware and internal wiring depends mainly on raising the required funds, the value of the hardware and network connections hinges on the quality of the courseware and teachers' ability to integrate it into the curriculum.

Consequently, the deployment process will need to be staged over several years, allowing time for schools and districts to secure adequate funding to cover not only the costs of initial deployment but also ongoing operations and support; for teachers to build skills and develop confidence with the technology; and for courseware developers to produce a wider variety of high-quality curricular materials. During this multiyear deployment period, committed leadership will be critical at the local, state, and national levels to provide direction and sustain momentum for this effort.

The NII offers access to information, services, and people

The NII includes the Internet and other public and private networks accessible through computers, video equipment, or telephones. Collectively, these networks offer schools a wide range of information resources and services, including up-to-the-minute news reports, electronic libraries of government documents, electronic bulletin boards for debate of educational issues, multimedia "edutainment" products, on-line encyclopedias, and National Geographic's Kids Network.

Just as important, the information superhighway can connect students to a broad spectrum of human resources: teachers at other schools (including colleges); experts from museums, libraries, archives, and research institutes; and other students from around the world. Parents and other community members can become more involved in the educational process, as well, by dialing into the local school's network from home computers, from equipment made accessible through local libraries and community centers, or at the school itself if it provides after-hours access. The connection to the NII greatly expands the information resources available to students and teachers, and creates new channels for communication.

To illustrate: a typical morning at a middle school connected to the information superhighway might begin as one group of students arrives early to update the school's home page on the World Wide Web. This home page signals to other schools that also have electronic access to the Web that they have a sister school here whose students and teachers are interested in exchanging ideas about world events and other educational topics. At the same time, another group of early arrivals works with the vice principal to prepare the morning broadcast. Each school day formally starts with a live television presentation about the day's events; these presentations are written, directed, and produced by rotating teams of students and broadcast internally to all the classrooms. In the quiet minutes before this broadcast airs and classes start, a young language teacher is using his desktop computer to access an electronic bulletin board to see how language teachers from schools across the state have responded to his question about the best ways for explaining prepositions. Meantime, the principal is reviewing the electronic mail that parents sent her the evening before, prior to sending voice mail to all her teachers suggesting a schedule for the upcoming parent-teacher "open house."

Later in the morning, in a first-period modern history class, the same video technology that carried the local morning broadcast now enables this class to tour the Smithsonian's aerospace museum. In the classroom next door, the subject is anthropology. Students are grouped in teams of 3 and 4 around the classroom's computers, engrossed in a computer simulation that allows them to play the role of archaeologists on-site in Egypt, exploring ancient Egyptian culture as revealed

in its artifacts. In a classroom down the hall, each individual student is working math problems pitched at exactly the pace and level of difficulty appropriate for him or her, and getting immediate feedback on the answers, thanks to interactive software. At the same time, students in a writing class are drafting an essay assignment on their computers and employing electronic mail to get rapid feedback on their work from their peers....

Potential benefits of connecting are significant

None of the above is science fiction. These kinds of activities are taking place in innovative schools around the nation right now. And the early evidence from these schools suggests that in addition to exciting and engaging students, connection to the information superhighway can support important educational goals. At a minimum, connectivity promotes the computer literacy and networking/information skills that are prerequisite to an increasing number of jobs. By the year 2000, as much as 60% of American jobs may require such technology skills. In addition, by providing easier, faster, and more efficient access to a wide array of courseware, connectivity supports and enhances computer-assisted instruction, which has been proven effective in helping students master traditional academic subjects such as mathematics, science, and writing.

Many schools have experienced significant improvements in student performance after introducing computer-assisted instruction. For example, the Carrollton City School District in Georgia established a computer lab, among other changes, to reduce the failure rate in 9th grade algebra from 38% to 3%. In New Jersey, the Christopher Columbus Middle School saw student performance rise from well below to above state averages on standardized tests in reading, language arts, and math after the school implemented reforms that included extensive use of networked computers. The academic literature confirms technology's role in these improvements: a review of 254 controlled studies concluded that appropriate use of computers in the classroom reduces the time needed to master certain types of knowledge by as much as 30%. Put another way, in three school years, students benefiting from computer-assisted instruction can learn almost a full year's worth of material more than students who do not have access to the technology.

Furthermore, case studies suggest that when technology is integrated into the curriculum, it can support new teaching methods that emphasize critical thinking and investigative skills. For example, researchers have found that among students in California's Hueneme School District, average critical thinking abilities increased from the fortieth percentile to the eightieth percentile over the 12 years that the district has been integrating educational technology, including computers and electronic networks, into its classrooms.

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Many options for connecting are available today—and affordable

While the coming years will see important technological advances such as wider availability of broadband networks—with their greater speed, capacity, and transmission quality—the basic technology needed for connecting schools to the information superhighway already exists today. However, connecting requires more than just the external connection from a school to the NII. It also requires a local area network at the school to link the equipment; computers, video equipment, and other hardware; electronic content in the form of multimedia courseware, educational video programs, and on-line services; professional development programs for teachers and other school professionals; and ongoing technical support.

To date, few public K-12 schools have assembled all the required elements of technology infrastructure. For example, while on average there are 14 multimedia-capable computers per K-12 school, distribution of these computers is highly uneven across schools. Some schools have many, others few. And while up to 50% of schools have already installed local area networks, less than 10% of these networks connect computers in all classrooms; most just connect administrative computers or a few classrooms. Similarly, almost all schools have telephone lines, but they are primarily used for administrative purposes—only 12% of classrooms have telephones.

There are many possible approaches to putting all these elements of technology infrastructure into place so that public K-12 schools can successfully connect to the NII. To provide a framework for considering the wide range of options for deploying the technology infrastructure, this report describes a series of deployment models that assume different timeframes (i.e., deployment to all public K-12 schools by the year 2000 versus by 2005) and different levels of technology infrastructure (e.g., connecting all classrooms to the NII versus connecting one multimedia lab per school). These models were chosen because they represent the prototypical technology choices that schools are actually making, and because they illustrate the key economic breakpoints among different levels of technology infrastructure—that is, the step functions in cost. The models focus on connecting to the information superhighway via networked computers. In addition, the report describes the costs of providing public K-12 schools with interactive video equipment, classroom telephones, and voicemail.

The costs associated with the computer-based models illustrate the size of the funding challenge. For example, connecting a computer lab with 25 multimedia-capable computers to the NII in every public K-12 school by the year 2000 would consume 1.5% of the currently projected education budget for 2000 (which would be the peak year of expenditures, assuming phased deployment over 5 years). The cost

of connecting every classroom in every public K-12 school by 2005 would represent 3.9% of the projected 2005 education budget (again, the year of maximum expenditures, assuming phased deployment over 10 years). Adding telephones, voice mail, and business quality video to the classroom model would require an additional 0.4% of the education budget.

Using today's spending as a benchmark, schools are not that far from the Lab model: schools currently spend 1.3% of the public K-12 education budget on similar technology. However, while school spending is close to the Lab model on average, the 1.3% figure include schools that spend more, and are consequently well down the road of technology deployment, and those that spend less and would have to begin nearly from scratch.

The models include both initial and ongoing costs for deployment. They include all investments needed to buy, install, operate, and maintain the equipment, as well as the costs of technical support staff and professional development for teachers. Not surprisingly, in all models purchasing and installing hardware constitutes the largest initial cost. But funding for substantial ongoing maintenance and support is also essential for successful deployment. During the period of deployment itself, professional development for teachers is the largest of these ongoing costs. By contrast, the actual costs of connection (e.g., Internet access, telephone bills) represent a relatively small part of overall expenditures.

Three challenges must be addressed

Once a school or district has set goals for infrastructure deployment, the pace of progress will depend primarily on the availability of funding, adequate development opportunities for teachers and other school professionals, and appropriate courseware. Each of these factors is critical for successfully connecting schools to the NII.

While the **funding** challenge in aggregate sounds reasonable, it must be noted that numerous pressures are squeezing education budgets at the national, state, and local levels. The funding picture is further complicated by the fact that educational technology is unevenly distributed across public K-12 schools. As mentioned above, some schools have already established an integral role for computers, video, and networks in their curricula. Many have experimented with the technology in a limited way. Others have yet to launch—or identify funding for—their first experiments.

It should nonetheless be possible to meet the funding challenge through a combination of cost reduction, reprogramming existing funds, and additional initiatives from the public and private sectors. In the area of cost reduction, for example, steps such as bulk purchasing taken

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at the state or national level would reduce costs further than a typical district could on its own. In addition, certain categories of the school budget bear some relation to spending on technology infrastructure and thus might be reprogrammed to support connecting to the NII. For instance, a portion of the textbook budget might be shifted to acquiring on-line instructional materials. Finally, innovative schools across the country have secured funding through partnerships with corporations and community organizations.

Providing adequate **development opportunities for teachers and other school professionals** is the second critical factor for successful deployment. Teachers play the pivotal role in integrating the technology into the curriculum and facilitating its day-to-day use. But nearly 50% of today's teachers have had little or no computer experience, much less the training and confidence they need to fully integrate networked computers into their classroom teaching. The educational system currently offers little incentive to motivate teachers to build and apply technology skills. Incentives will need to be created and state certification requirements, teacher college curricula, and in-service training programs will need to be revamped to address technology skills. Providing development opportunities for other school professionals is also essential. School librarians, media specialists, and administrators often make decisions about technology purchases and advise teachers on technology use.

Finally, the value of the hardware and the network connections depends heavily on the quality of the educational materials they deliver. Meeting the diverse curriculum needs of all public K-12 schools will require a broad assortment of high-quality **courseware**. Currently, production of such courseware is limited because the market for such products is still relatively small. Widespread commitment to connecting the public K-12 schools to the information superhighway would accelerate growth of this market, which in turn would accelerate production of high-quality courseware. In addition, slow and cumbersome public school budgeting and procurement processes could be streamlined to speed up adoption of new courseware and make it easier for courseware developers to enter the public school market.

Connecting all public K-12 schools will take time—and leadership

Successfully connecting America's public K-12 schools to the NII involves coordinating several elements. Each school or district will need to make the commitment, and to make decisions about how much technology to deploy (connect one lab? every classroom? every desktop?) and how fast (establish lab-level connection by 2000? build out to the classroom level by 2005?). In making these decisions, the school or district will also need to identify adequate funding both for

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installing the technology infrastructure and for supporting it going forward. Funds may come from multiple public and private sector sources; tapping this range of resources will often require both diligence and creativity. To make sure that the technology—once funded—is applied effectively in the classroom, teachers will need the opportunity, incentive, and support to experiment with it, master it, and learn to adopt and adapt it as a basic teaching tool. Finally, as more schools make commitments to connectivity and acquire funding, and as more teachers become excited about teaching with the NII, the demand for courseware will grow. In turn, this will stimulate development of more and better courseware for teachers to choose and adapt for their classrooms.

These elements will have to be addressed in parallel and the effort needs to begin now, because bringing the elements together will take time. It will require the sustained efforts and contributions of leaders at all levels—school, district, community, state, and federal. In each school and district, it will be necessary for local leaders to communicate a compelling vision, set clear goals, and generate enthusiasm for connectivity.

The deployment process has to be "bottom-up" by nature, since without the commitment of teachers, principals, school boards, parents, and other community members, little change can take place in the classroom. The leadership required to encourage local deployment, spur courseware development, help teachers build new skills, and secure budget funds, grants, donations, and subsidies, will need to come from both the public and private sectors. To some extent, this process has already begun, and leaders are emerging. But without broader intervention, the process will likely be slow and inequitable. While no single blueprint for deployment can meet the diverse needs of every school district, it is equally true that individual schools will need help in marshaling resources and moving forward.

Strong leadership has been a key success factor in every case study we examined. Local leaders at innovative schools like the Ralph Bunche School in New York City, the Carrollton City School District in Georgia, and the schools in California's Hueneme District have pioneered the way, and students in those schools are already profiting from the educational benefits of technology. Actively encouraging experiments and initiatives in many more schools and districts around the country could result in widespread and significant improvements in American education.

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INTRODUCTION

Giving the nation's public K-12 schools access to the national information infrastructure (NII)—or "information superhighway"—over the next 5 to 10 years could produce significant educational benefits. But, realistically, what would it take to accomplish this? Would it be technically feasible in that timeframe? How much would it cost? Where would the major challenges arise?

At McKinsey & Company, Inc., we developed a fact base and perspectives to help policymakers and educators address these and related questions.* This report, which was prepared as a submission of information to the National Information Infrastructure Advisory Council (NIIAC), summarizes our analysis of options for connecting the nation's public K-12 schools to the information superhighway. The report incorporates insights on connecting to the NII drawn from visits to schools and interviews with educators, policymakers, and technology experts around the country, as well as from a review of the available literature on the educational uses of technology and connectivity.

The report begins with a summary of the principal applications and benefits of connecting public K-12 schools to the NII. (See also the sidebar "What Is the NII?" which briefly describes the key elements that make up the information superhighway.) Then, to illustrate the costs and highlight the challenges of capturing those benefits, the report describes a series of models for deploying the required technology infrastructure—that is, for putting into place the needed connections,

* The working team included Mark Evans, Sue Forbes, Ted Meisel, Michael Moore, Mike Nevens, Scott Rudmann, Margot Singer, Dennis Sweeney, and Karen Tate.

hardware, content, and human resources. The next section identifies the three major challenges to successful deployment—funding, professional development for teachers, and courseware development—and outlines a number of potential ways to clear those hurdles. The report concludes by highlighting some of the leadership challenges posed by technology deployment, underscoring that success will ultimately depend on the creativity and sustained commitment of leadership at all levels—school, district, community, state, and national.

This report does not attempt to lay out a national blueprint for infrastructure deployment, nor does it recommend specific public policy goals. Each school or district has its own unique needs, opportunities, and challenges; no one blueprint could possibly address them all. Accordingly, successfully deploying the infrastructure will require an approach flexible enough not just to allow individual schools to set their own pace and priorities, but actively to encourage local experimentation and innovation. In addition, this report does not evaluate the relative merits of competing demands on educational funding (e.g., more computers versus smaller class sizes). We recognize that educators and policymakers will have some difficult choices to make in determining the appropriate budgetary priorities and tradeoffs. To assist such deliberations, this report provides an economic analysis of various options for connecting schools to the NII. We hope that this analysis will inform the public debate on actions to take at the school and district level as well as provide a useful fact base for analyses and recommendations developed by the NIIAC.

WHAT IS THE NII?

Across the country, students in a number of schools are already connecting to the national information infrastructure (NII), also called the "information superhighway," and tapping into an array of resources that can help them build valuable information, computer, and networking skills.

The NII Is composed of electronic networks

The NII is a collection of electronic networks providing access to applications—programs, services, and communications—via computers, telephones, and video equipment. It comprises thousands of local area and wide area networks. Local area networks connect computers, printers, and other equipment in one room or building. Examples of local area networks include the electronic linkages among desktop computers present in most business offices and school computer labs, or the connections between the computers at the local Department of Motor Vehicles office. Wide area networks link devices in multiple or distant locations, like the public telephone system that transmits telephone calls or the cable television system that distributes programming throughout a city. The Internet, which many people use to link computers together, is yet another wide area network and one that is employed by many schools. Wide and local area networks can transmit information using telephone lines, cellular networks, satellite links, cable systems, or some combination of these.

A network typically increases in value as more users gain access to it. The public telephone network is valuable because almost everyone has a telephone and uses the network. Likewise, fax machines quickly became required business tools once enough machines were in use. The same is becoming true of computer networks. Electronic mail addresses, once the province of computer nerds and academics, are now becoming common.

Networks deliver applications

A growing range of applications are available through the NII. On-line services like America On-Line, Prodigy, and Compuserve (which include wide area networks) allow users from around the globe to access many types of information, like stock market quotes or entertainment listings, and to electronically purchase services, like floral deliveries or research requests. Communities such as Charlotte, North Carolina, have networked the public library and government offices to provide residents with access to job listings and announcements of community events. Video and telephone conferences are available through the NII from a variety of service providers. These applications and services will keep expanding as technology evolves and on-line activity grows.

Many educational applications can be found on the information superhighway. For example, National Geographic's Kids Network allows students from around the country to participate jointly in science experiments on-line. Channel One delivers education-focused news programming to thousands of schools each morning through its satellite system. Cable in the Classroom, a consortium of cable operating companies, delivers over 500 hours of educational programming each month. Students in rural parts of the Guilford County, North Carolina, school district are now able to take pre-college physics—from a teacher at another, larger high

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school—by using the district's new distance learning facilities and connection to the North Carolina Information Highway. Administrators in a California school district use a videoconferencing system that operates over the local cable television network to discuss best practices and new policies; these conversations rarely took place before. In a number of districts, students, teachers, administrators, and parents are discovering the increased communications made possible by electronic mail. Similar to the broader business and consumer uses of the NII, the quality and quantity of available educational services will expand as the NII develops.

The foregoing describes a little of what a school can do with network access. But not all educational applications are being delivered over networks today. In fact, many high-quality educational applications are available in "stand-alone" format. A host of course materials are available on videotape and laserdiscs. Skill-building CD-ROM simulation programs and other software for computers account for the vast majority of electronic content sold today to the schools. The line between stand-alone and networked applications is not always clear, however. As networks develop, many applications available only in stand-alone form may be delivered more cheaply and conveniently over networks in the future.

Different applications require different bandwidths

The services accessible by any given user depend on the platform (computer, video or voice) and bandwidth available to the user (see Exhibit 1: "Applications Landscape"). Bandwidth refers to the amount of information that can be transmitted over a network within a given time. Just as only so much water can flow through a 12" drain pipe, networks also have capacity limitations. These limitations are typically measured by the number of pieces of digital information, or "bits," that can be transmitted per second. Typical telephone lines (called POTS lines) are technically capable of moving up to 34 thousand bits per second (kbps), though 14.4 kbps connections are most common today. To the average student connected to the Internet via a telephone line, this means waiting 30 seconds or more for one full-color computer screen of information. However, faster telephone services are becoming more widely available. ISDN ("Integrated Services Digital Network") lines provide for speeds starting at 56 kbps, which significantly reduces the time required to receive one screen of information. And some schools are accessing networks through high-speed T-1 telephone lines, which operate at over 1.5 million bits per second (mbps) and allow 24 students fast, concurrent access to networks.

There are certain applications that require even more bandwidth, like the amount available through fiber optic or coaxial cable. These new services make extensive use of audio and video, and include video-on-demand, desktop videoconferencing and whiteboarding, virtual field trips via video networks, and networked simulations. At least one company, The Lightspan Partnership, plans to use high-speed broadband networks and video equipment to transmit interactive curricular materials into both classrooms and homes. While most of the educational applications available today do not require fast, high-capacity broadband connections, greater bandwidth would enhance the quality and speed of existing applications, as well as encourage developers to take advantage of the new capabilities.

WHAT IS THE NII?

Bandwidth availability is growing

How fast can the average school expect to gain access to broadband networks? Although the answer is quite uncertain, it seems likely that broadband will not be widely available until sometime in the early 21st century. The answer depends on a number of developments in the regulation of telecommunications companies, the state of competition between those providers, and market demand for enhanced services requiring broadband technology. Some states—including North Carolina, Iowa, and Hawaii—have taken steps to accelerate the deployment of broadband networks in the public realm. Schools in these states have access to such networks today, though some find the price high relative to other technology items. Other states, including Kentucky, are currently in the process of designing their broadband networks. While such efforts are important, schools can get started on connecting to the information superhighway now, even if they do not have broadband access yet.

Exhibit 1

APPLICATION LANDSCAPE EXAMPLES

Platform	Stand-alone or one way	Narrowband	Wideband	Broadband
Dedicated voice		• Telephony • Voicemail		
Dedicated video	• Prerecorded programming • Broadcast programming		• Distance learning* • Video-conferencing*	• High-quality interactive video • Video-on-demand
Computer-based	• CD-ROM or disk-based software - Simulations - Drill and practice	• E-mail • Discussion forums • Access to data resources • Text-based networked courseware	• Worldwide web • Desktop video-conferencing/whiteboarding • Multimedia courseware	

Bandwidth**

* Business quality with ISDN; professional quality with TI (assuming existing compression technology)

** Required bandwidth also depends on number of concurrent users

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BENEFITS OF CONNECTING TO THE NII

Connecting public K-12 schools to the NII could produce a variety of educational benefits. Clearly, it would enable students to build computer and networking skills. Early evidence indicates that it could also support both traditional teaching approaches and new methods oriented toward teaching problem solving and critical thinking skills. Certainly, students find the technology exciting and engaging, it provides them access to a wide range of information resources, and it opens up communication with subject-matter experts, other students, and teachers.

Providing students with access to networked computers helps prepare them for the economy and society they will face in the 21st century. Basic competence in the use of computers and electronic networks is becoming a fundamental requirement for employment in the better jobs in the U.S. economy. According to research conducted by the Children's Partnership, 47% of jobs in 1993 required computer and/or networking capability—up from 25% in 1984.[1] By the year 2000, this study forecasts, 60% of jobs will require these skills and will reward them with a 10-15% pay premium over jobs that do not require such capabilities. In addition, the growing availability of on-line information and research resources gives a competitive advantage to students and workers who can effectively use these tools in their studies or jobs.

[1] *America's Children and the Information Superhighway* (Washington, D.C.: September 1994).

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These facts alone convince many educators and policymakers that connecting schools to the NII, and thus giving public school students exposure to computers and networking, is important. In addition, demonstrating that computers and connection to the NII can make a fundamental difference to students' achievement in academic subjects would persuade a broader constituency about the importance of deploying this technology in the schools.

To date, the evidence is strongest concerning the use of standalone computers in teaching. Currently, stand-alone computer applications are both the most widespread[2] and well-researched use of technology in classrooms. *The Effectiveness of Technology in Schools, 1990-1994*, presents a comprehensive review of over 130 recent academic studies.[3] The review found that using technology to support instruction can improve student outcomes in a wide range of subjects, including language arts, math, social studies, and science. In a study of writing skills, for example, researchers found that the papers of eighth graders using word processors were consistently superior to handwritten papers in mechanics, organization, and focus.[4] In another study, third and fifth grade math students received either computer-assisted instruction (CAI) or traditional classroom instruction for 71 days. The students who received CAI demonstrated gains, measured in months of grade placement, about twice that of the students receiving traditional instruction.[5] Since the study was controlled for time on task, the results were largely attributed to the effectiveness of CAI. Even more striking, the study quantified the cost of gaining a month of grade placement by various methods, and concluded that CAI was a more cost-effective approach to raising mathematics scores than tutoring, increased instruction time, or reduced class size.[6]

The use of computers seems to have even greater effects with low achieving and remedial students. A review of New York City's Computer Pilot Program, focused on educationally disadvantaged students, found that participating students achieved gains of 80% for reading and 90% for math.[7] In a review of 20 studies of the effect of word processing on writing quality, researchers found a 27% improvement

[2] See University of California, Irvine, Department of Education, *Analysis and Trends of School Use of New Information Technologies* (U.S. Department of Commerce, National Technical Information Service, 1994), pp. 30-44.

[3] Ellen R. Bialo and Jay Sivin-Kachala, *Effectiveness of Technology in Schools, 1990-1994* (Washington, D.C.: Software Publishers Association, 1995).

[4] Ronald D. Owston, Sharon Murphy, and Herbert H. Wideman, "Effects of Word Processing on Student Writing in a High Computer Access Environment" (North York, Ontario: York University Centre for the Study of Computers in Education, June 1991); discussed in *Effectiveness of Technology*, supra note 3.

[5] J.D. Fletcher, D.E. Hawley, and P. K. Piele, "Costs, Effects, and Utility of Microcomputer Assisted Instruction in the Classroom," *American Educational Research Journal*, vol. 27, no. 4 (Winter 1990), pp. 783-806. Students in the third grade demonstrated relative gains of 5.70 months for CAI versus 2.86 months for traditional instruction; for the fifth grade students, the gains were 8.89 versus 4.94 months.

[6] Ibid., pp. 800-802.

[7] F. Guerrero, M. Mitrani, J. Schoener and Swan, "Honing in on the Target: Who Among the Educationally Disadvantaged Benefits Most from What CBI?," *Journal of Research on Computing*

overall but a 49% improvement where remedial students were involved.[8]

A few reports have attempted to quantify the pattern of results emerging from the hundreds of individual studies. In a review of 254 controlled studies, researchers found that CAI helped students to learn 30 percent faster than students receiving traditional instruction.[9] The implication of this 30 percent gain is that students receiving CAI would gain a year relative to their peers for every three in school.

Many schools and districts have used CAI and other technology as part of their strategies to boost achievement. For example, the Carrollton City School District in Georgia implemented a computer lab, among other changes, to reduce the failure rate in 9th grade algebra from 38% to 3%. Students at the Clearview Elementary School, in Chula Vista, California, typically scored in the bottom 10% on standardized achievement tests until the school underwent restructuring, including the deployment of advanced technology. Within 2 1/2 years, test scores reached the 80th percentile.[10] The Christopher Columbus Middle School went from performing well below New Jersey state averages on standardized tests to above average in reading, language arts, and math within a few years of implementing reforms including extensive use of networked computers at school and home.[11]

The method by which stand-alone computer technology appears to deliver these benefits differs by subject. Student writing skills seem to improve because computers enable students to write two to three times as many words in the same amount of time and make rewriting much easier.[12] For subjects like mathematics, where symbolic logic plays an important role, computer applications allow students to visualize the concepts they are studying.[13] Computers also permit a greater degree of individualization in instruction: interactive software paces

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in Education (Summer 1990), pp. 381-403; discussed in *Effectiveness of Technology in Schools*, supra note 3, p. 9.

[8] Bangert-Drowns, "The Word Processor as an Instructional Tool: A Meta-analysis of Word Processing in Writing Instruction," *Review of Educational Research*, 63 (1), 1993, pp. 69-93; discussed in *Effectiveness of Technology in Schools*, supra note 3, p. 3.

[9] Chen-Li Kulik and James A. Kulik, "Effectiveness of Computer Based Instruction: An Updated Analysis," *Computers in Human Behavior*, 7 (1991), pp. 75-94. The technique used by the researchers is termed meta-analysis; it provides a method for normalizing results across studies employing different measurement approaches. To further put the results in perspective, 94% of the statistically significant cases reviewed favored CAI. See also A.W. Ryan, "Meta-Analysis of Achievement Effects of Microcomputer Applications in Elementary Schools," *Educational Administration Quarterly*, 27 (1991), pp. 161-184 (meta-analysis of 40 studies focused on elementary school children that also found 30% gains in learning). Another meta-analysis found an achievement effect of 50% from videodisc- and videotape-assisted instruction based on a review of 63 studies; see Barbara J. McNeil and Karyn R. Nelson, "Meta-Analysis of Interactive Video Instruction: A Ten-Year Review of Achievement Effects," *Journal of Computer-Based Instruction* (Winter 1991), pp. 1-6.

[10] Interview with Carol Welsh, Program Manager, 21st Century Education Initiative, Joint Venture Silicon Valley Network, September 1995.

[11] "The Haves and the Have-Nots," *Newsweek* (February 27, 1995), p. 50.

[12] Given at least 15 minutes of practice a day, third graders learned to type 20-30 words per minute with 95% accuracy over a six-week period. Third grade children typically write nine to eleven words per minute by hand. David Dwyer, "Apple Classrooms of Tomorrow: What We've Learned," *Educational Leadership* (April 1994), pp. 4-10.

[13] M P. Alexander, "The Effective Use of Computers and Graphing Calculators in College Algebra,"

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exercises at a tempo and difficulty level appropriate for the individual student, and provides immediate feedback and reinforcement.[14]

Networking and networked applications can support the use of CAI by making software more easily available to students; by providing wider access to skilled teachers, experts, and resources; and by creating opportunities for collaboration that make learning activities more engaging. For example, students using electronic mail have demonstrated significant increases in reading and writing skills.[15] In a controlled distance learning experiment, students at seven high schools received anatomy and physiology instruction via satellite, with a local science teacher facilitator, while students at another seven high schools received face to face instruction. The students receiving distance learning achieved "at a significantly higher level" than their peers. The difference may have been in the skills of the distance learning teacher.[16]

Today, many educators are focusing increasing attention on a cross-disciplinary teaching approach that emphasizes critical thinking, synthesis, and investigative skills. Based on interviews and visits to schools, we believe that connection to the NII and widespread use of computers have the potential to support this new approach. On-line resources give students rapid access to information from diverse sources in various forms. Thus, the challenge of finding the facts can quickly give way to the challenge of synthesizing and interpreting the facts. Simulation software develops problem-solving skills by allowing students to tackle life-like challenges and experiment with different solutions in real time. For example, the Dalton School's "Archaeotype" program places students in the role of archaeologists on a dig. They work in teams to access and analyze multiple sources of electronic, printed, and human information. Networking the computers further facilitates team-based projects in and across classrooms, building skills that many educators and employers believe are important for students' development.

Admittedly, the research literature is thinner with respect to technology's contribution to building critical thinking and synthesis skills.[17] Though researchers point to improved student ability to solve multi-step word problems,[18] or even 50% overall improvement in critical thinking ability,[19] the exact sources of these improvements are still difficult to isolate. But looking at what actually goes on in the classrooms of inno-

Dissertation Abstracts International, 54/06-A, 1993; discussed in *Effectiveness of Technology in Schools*, supra note 3, p. 32.

14 See F. Guerrero, et al., supra note 7.

15 See for example Patrick O. Rooney, *The Report of the Evaluation of the Model Technology School Program in the Hueneme School District* (Hueneme School District Board of Education, 1992).

16 E.D. Martin and L. Rainey, "Student Achievement and Attitude in a Satellite-Delivered High School Science Course," *The American Journal of Distance Education*, 7(1), pp. 54-61.

17 In part this is true because achieving benefits of this type requires many pedagogical changes, making it difficult to isolate the impact of technology per se. It is also true that longitudinal studies are needed to measure differences in student achievement over time; few if any such studies have yet been completed simply because connectivity in the schools is a very recent phenomenon

18 Cognition and Technology Group at Vanderbilt University, "The Jasper Series: A Generative

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vative schools makes these improvement figures seem reasonable. A visit to the Hueneme School District in California illustrates this point. As explained in the side bar ("Case Study—Hueneme"), this school district has, over the last 12 years, changed most aspects of its educational approach. New classroom layouts, new curricula, involvement of parents in the education process, and teacher-led innovation in instruction have all contributed to a dramatic increase in academic performance. Students seem highly engaged in the learning process, and teachers relish their new roles as coaches rather than lecturers.

Such vigorous and creative integration of technology into daily classroom teaching can bring about fundamental changes in the way schools carry out their educational mission. But it requires more investment in hardware, courseware, and professional development for teachers than would be necessary just to teach basic technology skills or support stand-alone computer applications. It requires more time to implement. And it requires the courage to be a pioneer: best practices for integrating technology into the classroom are still being discovered—they have not yet been meticulously researched and measured. However, pioneering schools like those in the Hueneme District have shown that students can benefit substantially from careful integration of technology into the classroom, supported by well-trained teachers.

Even when deployment is much less sweeping and sophisticated, connectivity still brings new resources to schools. Specialized teachers, subject matter experts, remote libraries and databases, and virtual field trips enrich the educational experience of students connected to the information superhighway. Distance learning, in which students participate in courses offered at other locations via video technology, can be especially useful for rural or inner city schools with limited resources. This interactive video technology enables these schools to expand their menu of courses and supplement their roster of teachers.

Connectivity further enriches the learning environment by providing new channels of communication. For example, electronic mail facilitates communication among students and their teachers, administrators and parents. Many students raise issues and ask questions through electronic mail that they would be reluctant to pose to an adult face-to-face. The Internet and other on-line services also allow students to communicate with a wide variety of professionals and other students around the world, broadening the educational community.

It seems clear that the impact on student motivation levels is significant. The Christopher Columbus School, which extensively uses networked computers, has its district's best attendance record for both students and faculty.[20] In the Carrollton District, the dropout rate declined from 19% to 5% after deployment of technology.[21]

Approach to Improving Mathematical Thinking," *This Year in School Science* (Washington, D.C.: American Association for Advancement of Science, 1991).

[19] Rooney, supra note 15.

CASE STUDY

HUENEME SCHOOL DISTRICT

Twelve years ago, students in the Hueneme School District scored right around the average in math, reading, science, and history compared to students in similar schools and districts in the state of California. Today, average student test scores in this K-8 district near Santa Barbara have risen to above the eightieth percentile. Perhaps even more impressive, academic researchers using the Cornell Critical Thinking Test have found that students' average critical thinking abilities have risen from the fortieth percentile to the eightieth percentile when measured against their peers.

Pinpointing the source of these dramatic improvements is difficult. But the teachers and parents in the Hueneme district attribute the difference in large measure to the fact that the last twelve years have been marked by a substantial investment in educational technology, including computers, networking, and teacher training. Today, the Hueneme district has one of the most advanced technology infrastructures in the nation, as well as a carefully crafted program for integrating technology into subjects as varied as science and history.

With nearly one computer per student distributed across classrooms and libraries, and video equipment in every room, Hueneme schools are well equipped on the technology front. But the teachers and the administrators have gone another important step by literally redesigning the physical layout of their classrooms to make optimum use of the technology and maximize teacher-student interactions. In Hueneme's "smart classrooms" students no longer sit in rows behind desks and listen passively to lectures. Instead, computers and video monitors have been integrated into "learning pods" in which students work together, facing each other.

This dynamic learning environment is supported by a number of networks that link schools in the district to each other and to the Internet and other national networks. All 11 schools, the district office and maintenance facilities have local area networks that are connected to the Hueneme Wide Area Network (HWAN) which, in turn, is linked to the Internet. Cable linkages, provided by the local cable company, Jones Intercable, Inc., connect all district classrooms to enable videoconferencing across the district. And one school, Blackstock Junior High School—a state of California Model Technology school site—has an advanced fiber optic local area school network, which will be replicated in other district schools within the next 12 months. This junior high is also connected to a national wide area network that includes several schools from other states and the MCI laboratory in Richardson, Texas.

For Hueneme students, technology and connectivity provide an exciting learning environment in which they can master educational basics while learning skills that prepare them for the future. At Blackstock Junior High, for example, each day begins with a live, school-wide video broadcast of the day's events that is scripted, produced, recorded, and transmitted over the internal video network by the students. With the touch of a button, students in a social studies class bring geography to life with digitized terrain maps, recordings of national anthems, and video clips of life and culture in other nations. Science students can watch and interact with computerized physics experiments—such as simulated stress testing of student-designed surfaces—that would be otherwise virtually impossible to carry out. A direct connection to the Lawrence Livermore Lab's Cray supercomputers allows students to review alternative strategies for solving complex math and science projects.

The dramatically changed learning environments in Hueneme did not appear overnight. Rather, they are the product of years of experimentation. The district started 12 years ago with one computer lab in a single school. Classroom use of computers began when one teacher agreed to spend a semester designing a science classroom with individual computer stations set up to teach different science concepts; the smart classroom was born. Since then, teachers have designed rooms for other subjects ranging from math to English to social studies and have utilized time away from instruction to design new curricula that take advantage of the new learning environments. In 1995, the twelfth-generation smart classroom design of learning pods and videoconferencing capability was unveiled for student use.

None of the benefits engendered by technology and connectivity in the Hueneme district would have been possible without the combined support of the district administration, school board, teachers, parents, and community leaders. The district superintendent, Dr. Ron Rescigno, has provided vision, leadership, and moral support to the critical agents of change, the teachers. "We have a clear focus on technology," he says. "The key is to keep experimenting—pushing the envelope—and then integrate what you learn into the next deployment of technology. Teachers here know they are taking risks when they use educational technology, but they know they have the support of the district. I don't think we are anywhere near to having perfected classroom use of technology. I don't know if we will ever perfect it. There will always be new developments to consider."

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Connecting schools to the information superhighway also helps teachers and others to better help students; in fact, connectivity can provide benefits for a wide range of stakeholders (see Exhibit 2: "Benefits to Education Stakeholders"). Importantly, network technology frees teachers from the isolation of the classroom. Communicating easily with other educators is a significant benefit for teachers who spend most of their time in the classroom and, consequently, have traditionally had little contact with other professionals with whom they could share experiences and ask questions. By contrast, today there are dozens of education-focused discussion groups on the Internet, addressing a wide range of topics from best practices in distance learning to reviews of new software and textbooks. For example, a science teacher we met in the Hueneme School District is constantly sharing his experiences using his school's new educational technology with other teachers through the Internet. Connecting to the NII helps teachers such as this one form a learning community that can advance a variety of educational goals.

Voice mail, electronic mail, and administrative applications (e.g., attendance-taking, grade record-keeping) can also improve communications among teachers, as well as parents and administrators. At the Math and Science Technology magnet school in Los Angeles, California, Greta Pruitt, the principal, told us: "E-mail allows teachers to pose questions to each other and to me when they have the time. On the system, we can respond to each other at our convenience and we avoid the 'let's talk later' syndrome that is part of working with children."

Parents also benefit through increased connection with their children's learning process. Linking parents to the school network—through home computers or through after-hours sessions at a school. library, or community center—can involve them directly in their children's education (e.g., by allowing them to follow along with homework assignments or to correspond more easily with teachers). At the Dalton School in New York, for instance, parents use electronic mail extensively to discuss classes and the performance of their children. Parents and children at the Union City school in New Jersey make use of the lab after-hours to work jointly on assignments.

While this report focuses primarily on the benefits the NII can bring to schoolchildren, the necessary infrastructure, once deployed, can clearly benefit other constituencies as well. Once in the school, computers and networks can provide wide access to services provided by the information superhighway. The Ralph Bunche School in New York offers use of its computers to parents, who come in after hours

[20] U.S. Department of Education. *Telecomputing for Teaching and Learning: Stories of People Using Computer Networking for Learning* (November 1994), p. 9

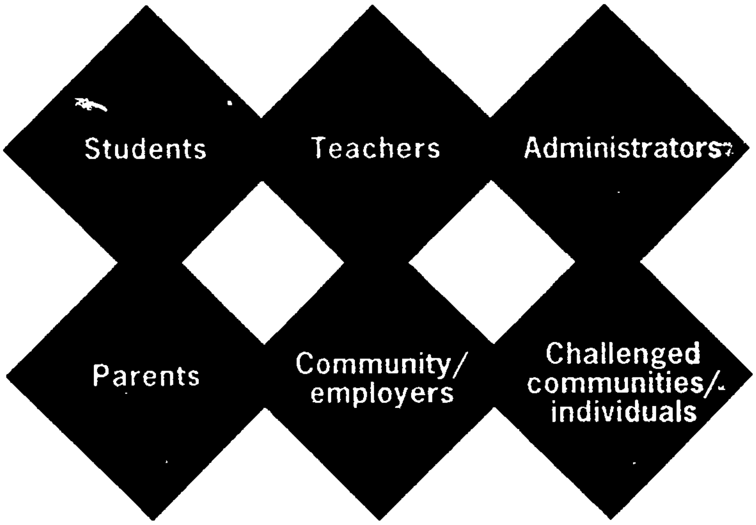
[21] For more information, see "Case Study: Carrollton School District, Georgia," infra p. 39.

Exhibit 2

BENEFITS TO EDUCATION STAKEHOLDERS

- Enables greater individualized attention to students
- Promotes communications with other teachers, school professionals, and outside experts
- Enhances productivity

- Promotes computer/network literacy
- Increases motivation to learn
- Increases learning/achievement
- Provides access to more resources
- Promotes communications with others



- Increases record-keeping efficiency
- Promotes communications with other professionals and teachers

- Increases access to student information
- Promotes involvement in children s education
- Promotes life-long learning

- Levels playing field by ensuring access
- Provides opportunity to be information producers and preserve culture

- Increases skills of work force
- Promotes community interaction

to develop computer and network literacy and accelerate their learning of English. In fact, activities such as these could potentially bring in revenue to help defray the cost of building technology infrastructure in schools.

It follows that as more schools network with each other, the possibilities for sharing learning multiply. The same principle applies to connecting schools with homes, local libraries, and community centers involved in promoting lifelong learning. Indeed, some communities in Tennessee, New Mexico, and elsewhere are now experimenting with community-wide networks that link up schools, libraries, community centers, and other organizations to provide a wide range of educational and social benefits for diverse groups of local stakeholders (see sidebar on "Libraries, Community Centers, and Community Networks.")

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LIBRARIES, COMMUNITY CENTERS, AND COMMUNITY NETWORKS

Schools are not the only community institutions that can provide NII-based services. Libraries and community centers are likely to be an important piece of the NII equation for most communities. These institutions can help educate children, support lifelong learning, provide public access to the information superhighway, and allow consumers of information to become producers of information in much the same way schools can.

Public libraries. Already responsible for providing information access and education programs, public libraries are well positioned to provide access to the NII. The specific infrastructure any given library would want to build is a function of its resources and the emphasis the community places on the many possible roles a public library could play.

Libraries currently support children's education through a range of reading, storytelling, tutoring and other programs; as places to do homework; and as information providers for student research. As many libraries have already discovered, computers and networks can add significantly to the library's tools. For example, the public library in Arlington, Virginia, recently acquired a multimedia computer along with educational and "edutainment" software; computer time is always in high demand. The award-winning Charlotte, North Carolina, public library has established three satellite centers with computer and network access to serve at-risk youth in their communities on weekends and after school.

Many state, county, and city library systems have launched programs to provide patrons with access to community and subject-oriented information specifically and to the information superhighway generally. The State of Maryland, Allegheny County in Pennsylvania, and the City of Seattle are among those who have initiated such efforts. For example, Maryland's *Sailor*, the state's on-line public information network, is currently available through hundreds of public library terminals. In addition to Internet access, *Sailor* provides information on city, county, and state government; libraries and education resources; and subject-oriented information on science and technology, entertainment and leisure, employment, and other topics.

In Allegheny County, Pennsylvania, the Electronic Information Network (EIN), a partnership between the Carnegie Library of Pittsburgh and the county library community, seeks to link Allegheny County's public libraries to each other and the information superhighway. As part of the EIN, Carnegie Public Library is also the headquarters and sponsor of the Three Rivers Free-Net. The Free-Net will provide access to the Internet as well as a place for community organizations to publish public service information. Information mounted on the Free-Net will include information on social service agencies, calendars of events, weather news, local government information, city guides, and consumer information.

Seattle Public Library's citywide network allows access to the Internet and local information resources through 200 public-use terminals in 20 neighborhoods and 2 housing projects. Dial-in and telnet connections are also available.

The Library's on-line activities include building a database of community organizations and a calendar of events, and compiling a "Seattle Facts" database. The library also provides access to the Washington State Legislature Public Access System, the City of Seattle Public Access Network, and the city's geographic information system, as well as important local community documents.

In addition to providing access, libraries have extensive experience and distinct capabilities in locating and organizing information. They can apply these skills in identifying, evaluating, and synthesizing information available through the NII as a service provided to community members, schools, and businesses.

Community centers. Community centers represent another possible entity—in addition to schools and libraries—that can advance the lifelong learning needs of communities, provide public access to the information superhighway, and even deliver social services. As with libraries, the applications, benefits, infrastructure options, and costs to provide NII access will derive from the specific role of the center in its community.

For the purposes of this discussion, we define a community center as a physical or electronic location where community members go to meet others, learn, play, or access information resources or social services. This broad definition encompasses a range of locations and a wide spectrum of potential roles. For example, the role of one community center could be to offer convenient, affordable access to the NII for the general public while another could be to provide targeted, programmatic access to the NII for at-risk groups. An example of the former role, Smart Valley in California is experimenting with placing Internet stations in a range of public locations including shopping centers, post offices, and town halls in order to better understand behavior and usage patterns. Examples of the latter role include a number of programs to expose inner city youth and other disadvantaged groups to technology. Plugged In of East Palo Alto, California, originally focused on at-risk youth in neighboring areas, has been expanding through partnerships to work with battered women's groups and rehabilitation centers. Currently, Plugged In offers programs on using computers, accessing the Internet, and working with various software packages. Some communities with limited resources may prefer to connect community centers ahead of schools or libraries. For example, a representative of a Native American community told us that Native Americans would be more inclined to accept and use NII-based tools if they were introduced in the tribal community centers rather than the public schools.

Some K-12 schools are serving as learning centers for members of their communities by providing after-hours access to distance learning and computer facilities. Mississippi's Project LEAP (Learn, Earn, And Prosper) is one such program; it uses satellite-based transmission in 200 K-12 schools to broadcast courses in reading, GED preparation, workplace readiness, and life-coping skills. These programs are broadcast after school hours from 4 to 9 p.m.

LIBRARIES, COMMUNITY CENTERS, AND COMMUNITY NETWORKS

Community Networks. In the broadest sense, a community could seek to be "wired" by networking a range of physical community centers as well as creating electronic communities that connect individuals or groups to each other and to community resources. While most are just in the planning stage, some community-wide networks are in operation today. The DIANE Project in Tennessee connects nearly 30 different institutions including universities, primary and secondary schools, libraries, science groups, local community centers, and small business groups.

Other communities have started by building community electronic bulletin boards that include public and private industry job listings, city permit applications, vehicle registration information, resources for starting up and growing small businesses, and announcements of emergency procedures. The La Plaza Telecommunity in Taos, New Mexico, is an on-line service and electronic community that provides educational services through Internet resources and distance learning; improved access to health care/medical information and resources (including Diabetes Knowledge Base for the local Pueblo Indians and prenatal care in response to the high incidence of teenage pregnancy); an electronic communications medium for debate of government and societal issues; and access to government information (including job listings from the New Mexico Department of Labor Service Center). Increasingly, discussions in some communities and among some government officials are focusing on how a broad set of social services could be delivered electronically, including welfare, health care, and home education.

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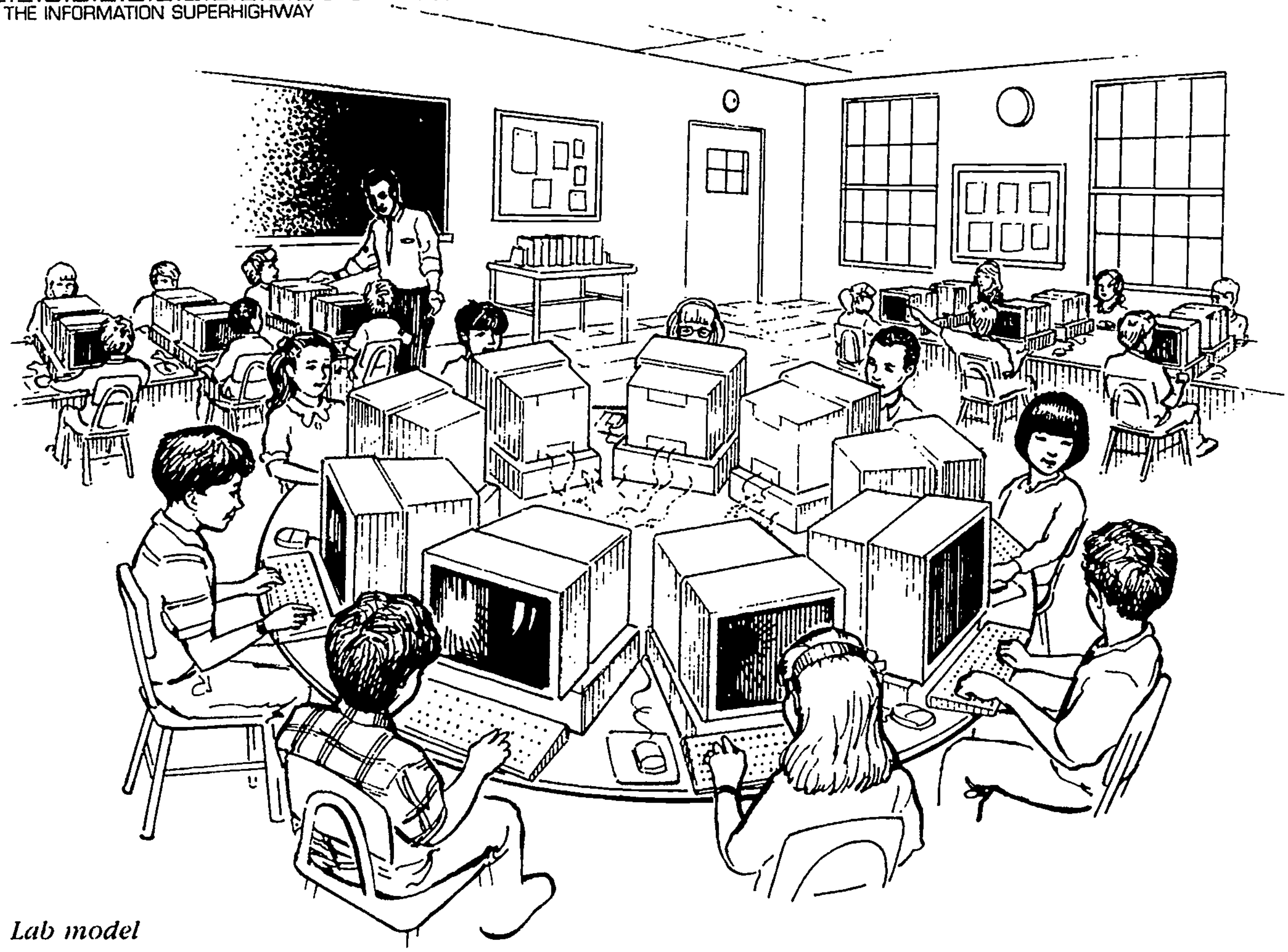
INFRASTRUCTURE OPTIONS AND COSTS

While the benefits of connecting to the NII appear to be significant, many policymakers and educators are concerned about how much it would cost to capture some or all of these benefits. To provide a framework for thinking about the range of options for deploying technology infrastructure in the public K-12 schools, and the costs of those options, we developed a sequence of models for deployment. These models represent prototypical infrastructure deployment choices that schools are actually making; they also illustrate the fundamental economic breakpoints among options.

The models focus on networked computers linked together and to the NII via wireline connections, except in rural locations where wireless connections are more feasible.[22] While deployment would actually take place at varying speeds in different schools and districts, we made the simplifying assumption here that each model will be implemented evenly over either a five-year or ten-year period (i.e., by 2000 or 2005). For each model, we evaluated the costs in detail across six infrastructure elements: (1) the connection to the school (i.e., the wide area networks that will connect schools to each other, to their district offices, and to the NII); (2) the connection within the school

[22] Although at a later point in the dissemination of broadband technology to residential communities interactive television sets may rival networked computers as a base for connecting to the NII, we focused on computer-based technology because it is widely available today. By the same token, although satellite and cable both represent important alternatives for connection, we focused on telephone connections because they offer two-way interactivity and are ubiquitous.



Lab model

(i.e., local area networks that will link computers within the given schools); (3) the hardware, including the computers, printers, scanners, and other equipment needed for full functioning of the technology; (4) content, including software and on-line service subscription charges; (5) professional development for teachers; and (6) ongoing system operations. Both video and voice options were evaluated as add-ons to the computer-based options.

Models of infrastructure deployment[23]

Briefly, the key features and associated costs of the computer-based models are as follows (see Exhibit 3: "Model Features" and Exhibit 4: "Estimated Cost of Deploying and Operating Infrastructure"):

- The basic "Lab" model envisions connectivity at the lab (or multimedia room) level for every public K-12 school by the year 2000. For each school, it includes 25 networked computers connected to the NII via 10 standard telephone lines (see Drawing: Lab model). This option only gives limited, scheduled access to teachers and students—for example, a given class of

[23] A detailed description of the models, their underlying assumptions, and the methodology for estimating costs may be found in Appendix A

Exhibit 3

MODEL FEATURES

Computer-based infrastructure

Lab
- Single room
- 25 computers
- Ethernet LAN in lab
- 10 telephone lines

Lab Plus

All of the above, *plus*
- Computer and modem per teacher

Partial classroom
- Half of classrooms: 1 computer per 5 students
- Ethernet LAN across and within all classrooms
- T-1 connection

Classroom

All of the above, *plus*
- All classrooms: 1 computer per 5 students

Common features*
- District server and LAN
- School server(s), printers, scanners
- Software, professional development, and support

* Extent of equipment, content, professional development, and support varies by model

Exhibit 4

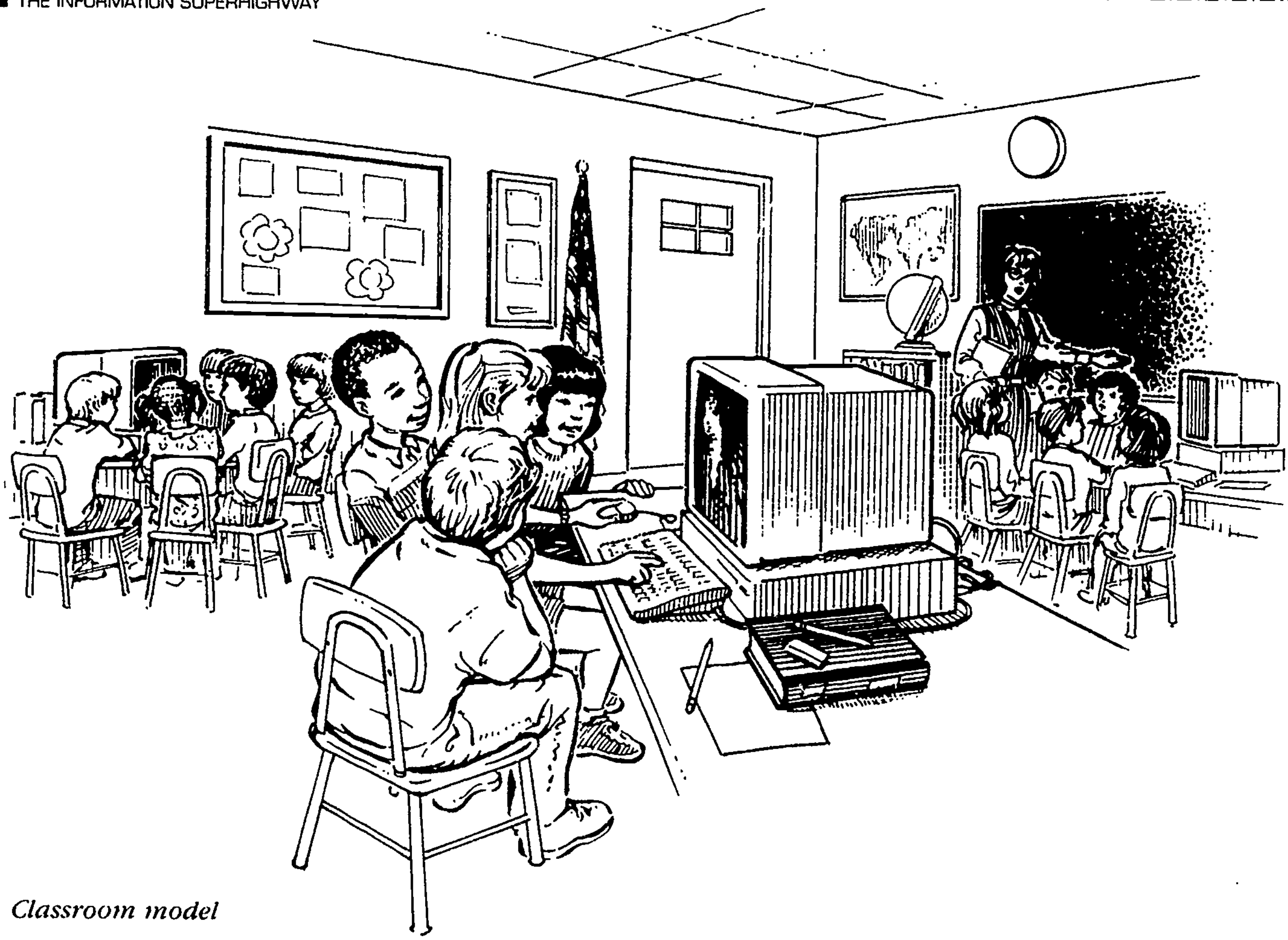
ESTIMATED COST OF DEPLOYING AND OPERATING INFRASTRUCTURE

Computer-based Infrastrusture

Model	**Total Initial deployment** $ Billions	**Annual operation and maintenance** $ Billions	**Public K-12 spending in final year*** Percent	**Deployed by year**
Lab	$11	$4	1.5%	2000
Lab Plus	22	7	3.0	2000
Partial Classroom	29	8	3.4	2000
Classroom	47	14	3.9	2005

* Reflects increase in education budget as forecasted by Department of Education (averages 5.6% per year through 2005 including inflation)

Source: National Center for Education Statistics; McKinsey analysis



Classroom model

students might be able to use the lab for one hour a day. Such intermittent usage requires a high level of commitment by all involved parties to achieve an effective level of integration into the curriculum. This type of set-up may be most appropriate for schools that are just beginning to experiment with technology and connectivity or where building basic computer and networking skills is the main focus.

One-time purchase and installation costs for the Lab model—deployed nationwide in all public K-12 schools—would total $11 billion during the five-year deployment period, while ongoing operation and maintenance costs would build over the deployment period to $4 billion per year once the infrastructure is fully in place. Another way of thinking about the cost is that it would represent 1.5% of the public K-12 education budget in the final year of deployment (the year that costs would reach their peak).[24]

[24] The final year of deployment represents the largest funding challenge. In the final year, the school is incurring the full load of ongoing operations and maintenance costs, in addition to the final installment of the one-time purchase and installation costs. Accordingly, costs in the final year of deployment represent the highest level that costs reach. For three of the four computer-based models presented in this report, the final year of deployment is 2000; for the Classroom model, it is 2005. Appendix A contains two more ways to represent the costs of deployment: per school and per enrolled student (see Exhibit 17: "Different Representations of Model Costs").

- In addition to all the technology assumed by the basic Lab model above, the intermediate "Lab Plus" model adds one computer and modem for each teacher. The rationale is to give teachers adequate exposure to the technology to expedite skill building and adoption of the technology.

  One-time purchase and installation costs would total $22 billion during the five-year deployment period, and ongoing operation and maintenance would cost $7 billion per year once the technology is deployed. Costs would represent 3.0% of the public K-12 budget in the year 2000, the final year of deployment.

- The "Partial Classroom" model assumes that half of each school's classrooms are connected with networked computers by the year 2000. The ratio is the same as with the Classroom model below: 5 students per computer with a T-1 connection (or substitute). Neither this model nor the Classroom model includes a computer lab. The Partial Classroom model is designed to illustrate a less costly variant—and possible step on the path—to the Classroom model. It also presupposes that some classes or teachers may be better starting points for deployment than others. For example, a school may choose to begin deployment in math or science classes or with teachers who appear particularly open to experimentation and change.

  One-time purchase and installation costs would be $29 billion over the five-year deployment period; ongoing operation and maintenance expenditures would equal $8 billion per year once the technology is deployed. Costs would represent about 3.4% of the public K-12 budget in the year 2000, the final year of deployment.

- The "Classroom" model connects every classroom of every public K-12 school to the NII through networked computers, at a ratio of 5 students per computer, using a T-1 line that transmits data, voice, and video at 1.5 mbps (or substitute if T-1 is not economically feasible). In this set-up, students work in small teams around the computers (see Drawing: Classroom model). Placing the computers directly in the classroom makes it possible to integrate the technology more closely into the curriculum than if the computers were in a lab. Teachers are able to incorporate computers and the NII in teaching the full range of subjects throughout the course of the school day, and students have easy access to the technology.

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Distance learning

One-time purchase and installation costs for this model would equal \$47 billion over the ten-year deployment period, while ongoing operation and maintenance costs would build over the deployment period to \$14 billion per year once the infrastructure is in place. Costs would represent 3.9% of the public K-12 budget in 2005, the final year of deployment.

- While we also considered a "Desktop" model that put a networked computer on every student's desk, it involved substantially greater costs. Initial installation costs were more than $3^{1}/_{2}$ times as high and ongoing costs $2^{1}/_{2}$ times as high as those of the Classroom model. For this reason, we did not examine the Desktop model in depth, even though the model might be desirable from an educational standpoint for schools or districts that can afford it. In fact, a few pioneering schools and districts, like Hueneme, have installed infrastructure similar to this model.

These models are based on weighted average costs taking into account different types of schools (e.g., old versus new, rural versus

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urban). All the models also take into account the currently existing infrastructure—that is, they make allowance in the costs for the computers and other infrastructure already deployed in the schools. Finally, they include estimates of future price declines in computers and other technology items.

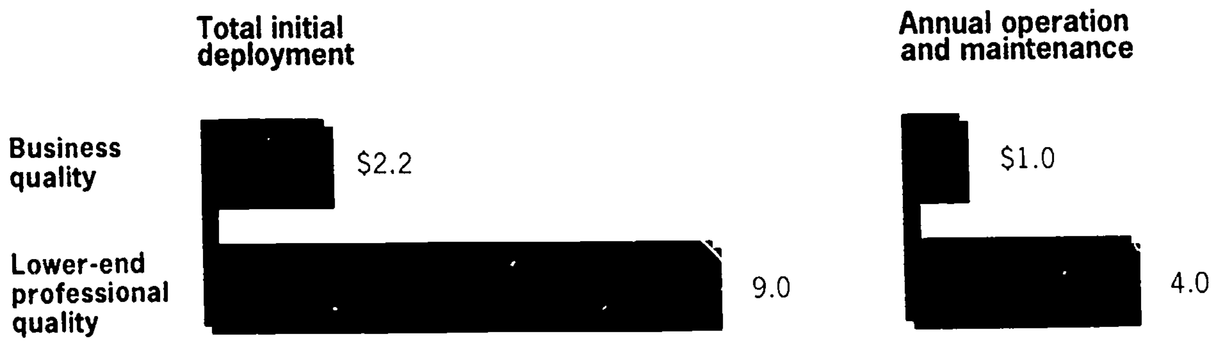
Adding video and voice capabilities

Costs for video equipment and operation, and for classroom telephones and voicemail, were calculated separately. Video equipment can deliver a range of educational benefits, from providing students access to educational materials available on videotape or videodisc to enabling classroom "field trips" to museums and historical sites. Distance learning, in which schools use video technology to allow students to participate long-distance in courses offered at other schools or colleges, can be especially valuable for rural or inner city schools (see Drawing: Distance learning).

The cost to provide video varies widely from installation to installation, however. On average, business-quality video, the quality of video most commonly used for videoconferencing today, can be added to computer-based deployment for a relatively nominal amount—for example, an additional 0.3% of the public K-12 budget for the Classroom model (see Exhibit 5: "Dedicated Video Infrastructure"). But some educational experts advocate the use of professional quality video where possible because it is more engaging for students,

Exhibit 5

DEDICATED VIDEO INFRASTRUCTURE*
Estimated Costs
$ Billions



* Incremental investment to classroom model; both video infrastructure options include professional development and systems operation costs

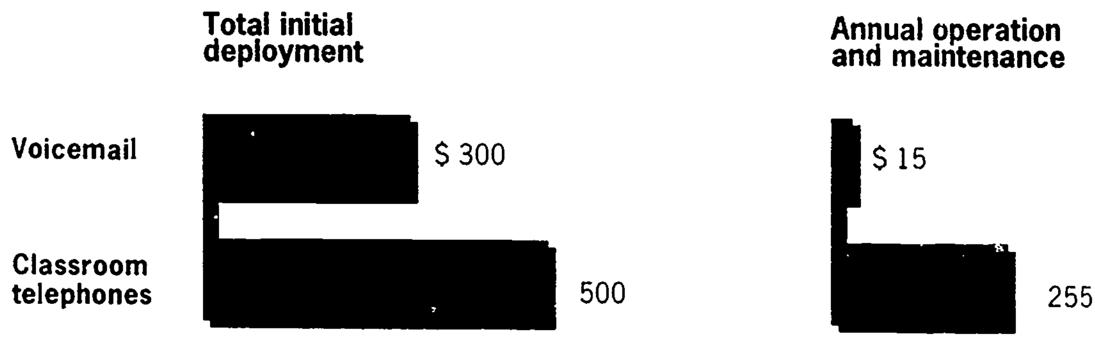
Source: Case studies; McKinsey analysis

Exhibit 6

DEDICATED VOICE INFRASTRUCTURE

Estimated costs

$ Millions



Source: Interviews; McKinsey analysis

who can be distracted by the jerky movements common to business-quality video.[25]

Installing high-resolution, professional-quality video increases the cost of deployment significantly. Some schools have spent up to $200,000 on equipment to create state-of-the-art facilities, and arranged for high bandwidth connections to produce better sound and images. For example, the Guilford County School District in North Carolina equipped all 16 of its high schools with high-quality equipment at about $100,000 per room, and connected this equipment to North Carolina's fiber optic information highway. Typically, Guilford County schools use their video system to deliver distance learning of advanced subjects like physics to students in rural areas of the district. Assuming less equipment investment than in the Guilford County example (approximately 35% less), a low-end professional-quality video facility would add approximately 30% to the Classroom computer-based model—or 1.2% of the public K-12 budget in the final year of deployment.

[25] Videoconferencing allows an image from a remote site to be displayed on a local party's television or computer screen, while a local camera simultaneously transmits an image to the remote party's screen, somewhat like a TV phone call. Business-quality videoconferencing typically features full-screen images, although these can be slightly fuzzy and may exhibit jerky motion, which some argue can fatigue viewers. Professional-quality videoconferencing, by comparison, features full-screen, full-motion, crisp video images. Unfortunately, it is also substantially more expensive than business-quality videoconferencing. Another video application, desktop conferencing, is growing increasingly popular. In desktop conferencing, individuals have video windows on their computer screens, with slightly fuzzy images and jerky motion. Desktop video is best used when face-to-face contact is required or body language is important, but it is too limited for classroom uses such as distance learning.

Classroom telephones and voice mail can also be added to the computer-based models relatively inexpensively (see Exhibit 6: "Dedicated Voice Infrastructure"). If the wiring for the telephone system is installed at the same time the local area network for the computers is installed, the additional costs are low. Telephones would add less than 0.1% to the funding challenge for the Classroom model if installed in conjunction with classroom wiring for computers, and voice mail would add even less than the costs incurred for telephones. Installing the telephones separately, however, would raise the overall price tag substantially.

Key findings about deployment costs

The models illustrate clearly that the biggest financial tradeoff hinges on how far into the school the technology is deployed—to the lab, the classroom, or all the way to each student's desk. But perhaps the most important finding from analyzing these models is that connecting public K-12 schools to the NII seems financially feasible. Connecting a computer lab to the NII in every public K-12 school by the year 2000 would require only 1.5% of the expected K-12 education budget in 2000 (the peak year of expenditures). By comparison, about 1.3% of public K-12 spending is already devoted to similar technology today. Thus, the Lab model could be deployed at a cost of 0.2% more than the public K-12 schools are currently spending on technology. Even connecting every classroom of every public K-12 school by the year 2005 would require only 3.9% of the expected K-12 education budget in 2005.

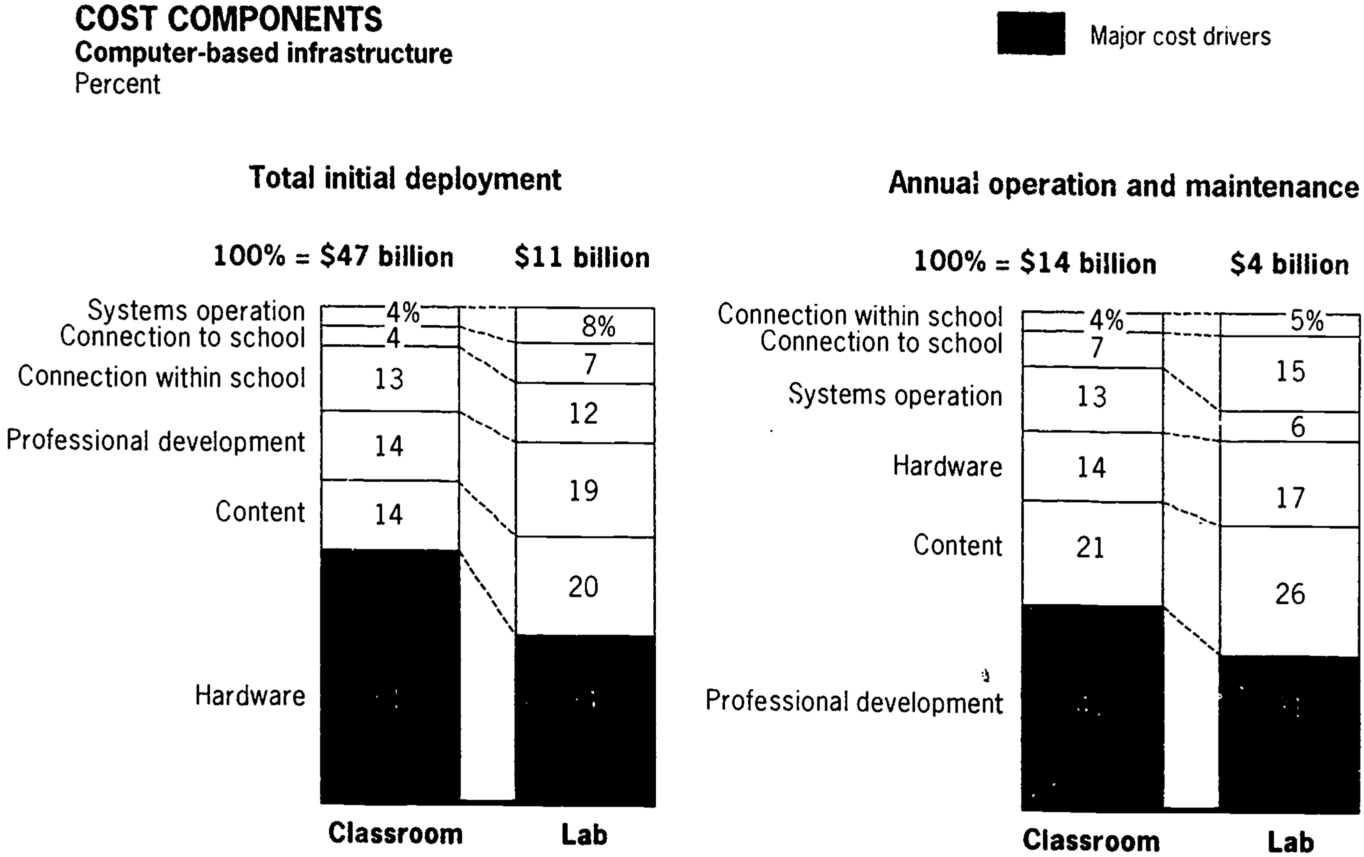
Analysis of these models reveals some other key insights about deployment costs, regardless of which model is selected (see Exhibit 7: "Cost Components"):

- Not surprisingly, purchase and installation of hardware constitute the largest upfront cost. On average, approximately 55% of the total hardware cost can be attributed to computers; 25% is printers, scanners, security and furniture stations; and 20% is retrofitting (upgrades for electrical and HVAC--heating, ventilation, and air conditioning).
- Perhaps less obviously, support and development for teachers and other school professionals constitute the largest ongoing cost during the 5 to 10 year period of deployment. Professional development includes formal training programs, on-the-job support from curriculum specialists, and use of the technology on the teacher's own time.

Exhibit 7

COST COMPONENTS

Computer-based infrastructure
Percent



Source: McKinsey analysis

- The cost of connection per se is a relatively small portion of the overall expenditures. In the Lab model, the portion attributable to connection to the school is 8% for initial deployment and 15% for ongoing costs; for the Classroom model, it is only 4% for initial deployment and 7% for ongoing costs. However, increased levels of usage over time could ultimately drive the relative cost of connection up. Depending upon the size of the up-front costs, the usage charges thereafter, and the potential need to upgrade for higher capacity at a later date, schools may want to consider installing a connection that has greater capacity (for supporting multiple users and carrying large amounts of data) than they need today or even project they will need in a few years.[26]

[26] For example, in certain states, some schools may find it more cost-effective to implement 5 ISDN lines instead of 10 POTS lines. The 5 ISDN lines, like the 10 POTS lines, permit 10 concurrent users—but with double the performance capability and the ability to handle video. Depending on the state tariffs, the 5 to 10 year cost for this additional capability could be fairly minimal—in fact, the extra $4000 in installation charges above that for telephone lines is likely to be quickly recouped in lower usage charges.

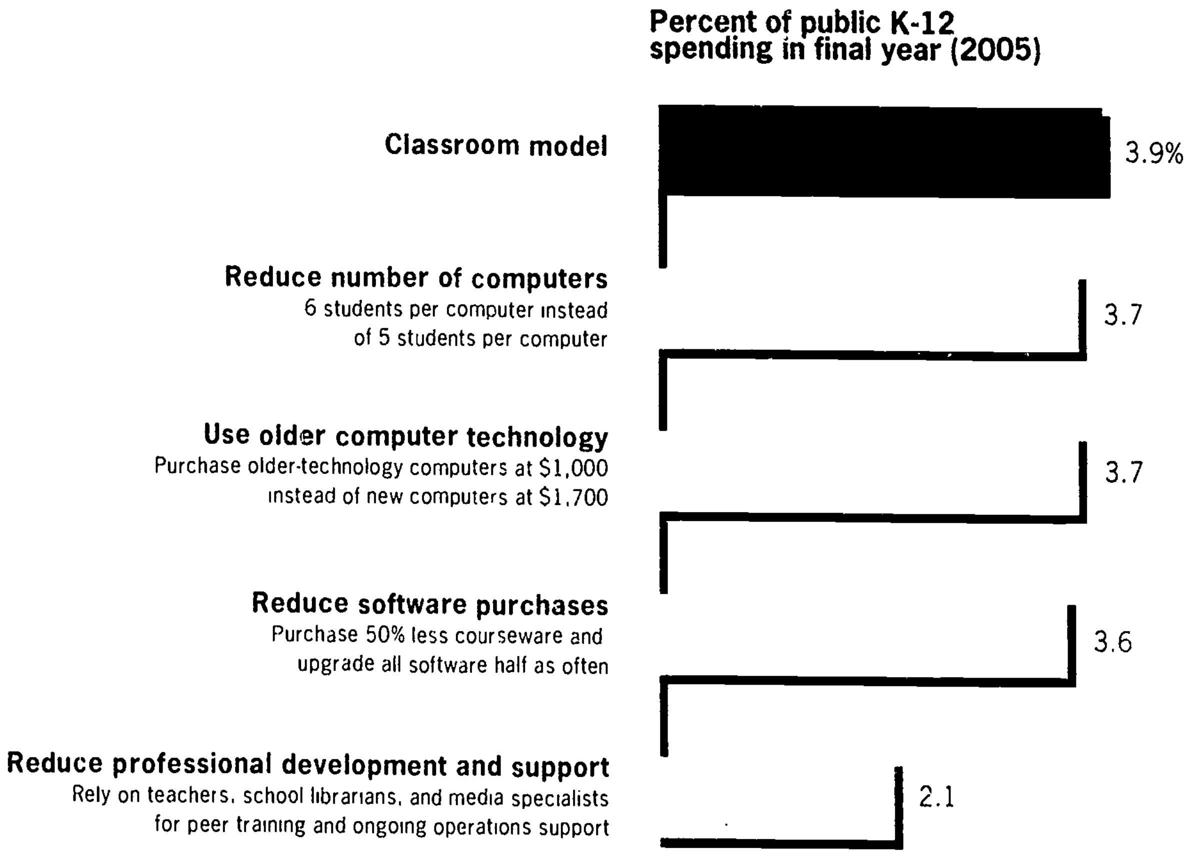
- Adding video equipment would not necessarily increase deployment costs substantially, depending on the quality of equipment selected.
- Classroom telephones and voice mail could be added fairly inexpensively—if the wiring is installed at the same time as the local area network for the computers.

Naturally, individual schools will deviate from the averages shown in the models. In particular, installation may be more expensive for older schools and connection could be more costly for rural schools. Older buildings are more likely to require substantial retrofitting in order to accomodate the installation of both hardware and local area networks. We calculated that, for the Classroom model, the local area network and hardware installation for a "typical" school implementing the Classroom model, would cost approximately $375,000 per school.

Exhibit 8

POSSIBLE LOWER-COST MODIFICATIONS TO CLASSROOM MODEL

Percent



Source: McKinsey analysis

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But these costs could be as low as $275,000 for new schools that have adequate HVAC capacity and wiring already built-in; they could also be as high as $800,000 for older schools with asbestos, inadequate electricity, insufficent HVAC capability, and a building structure that will not support a wireless local area network. Rural schools may find the wide area connections to be unavailable or prohibitively expensive. For example, a T-1 connection in a rural area could cost twice as much—$15,000 per school per year—as a T-1 connection in a non-rural area.

Trade-offs

While we believe that the models selected for analysis define a useful spectrum for consideration, they are only a few of many options. Individual schools and districts might choose other models and make different trade-offs between costs and potential benefits (see Exhibit 8, previous page: "Possible Lower-Cost Modifications to Classroom Model"). With all such choices, schools should carefully consider whether cost reductions will be sufficient to warrant the accompanying loss of educational benefits. For example, purchasing lower cost computers could substantially reduce initial deployment costs. However, computer capabilities dictate the range of applications students and teachers can use. Likewise, reductions in funding for teachers' professional development could significantly reduce the largest source of ongoing costs during the deployment timeframe, and yet teacher skill building is one of the most essential elements of effective implementation. Trade-offs could also be made between exploiting current technology versus experimenting with or waiting for more advanced technology.

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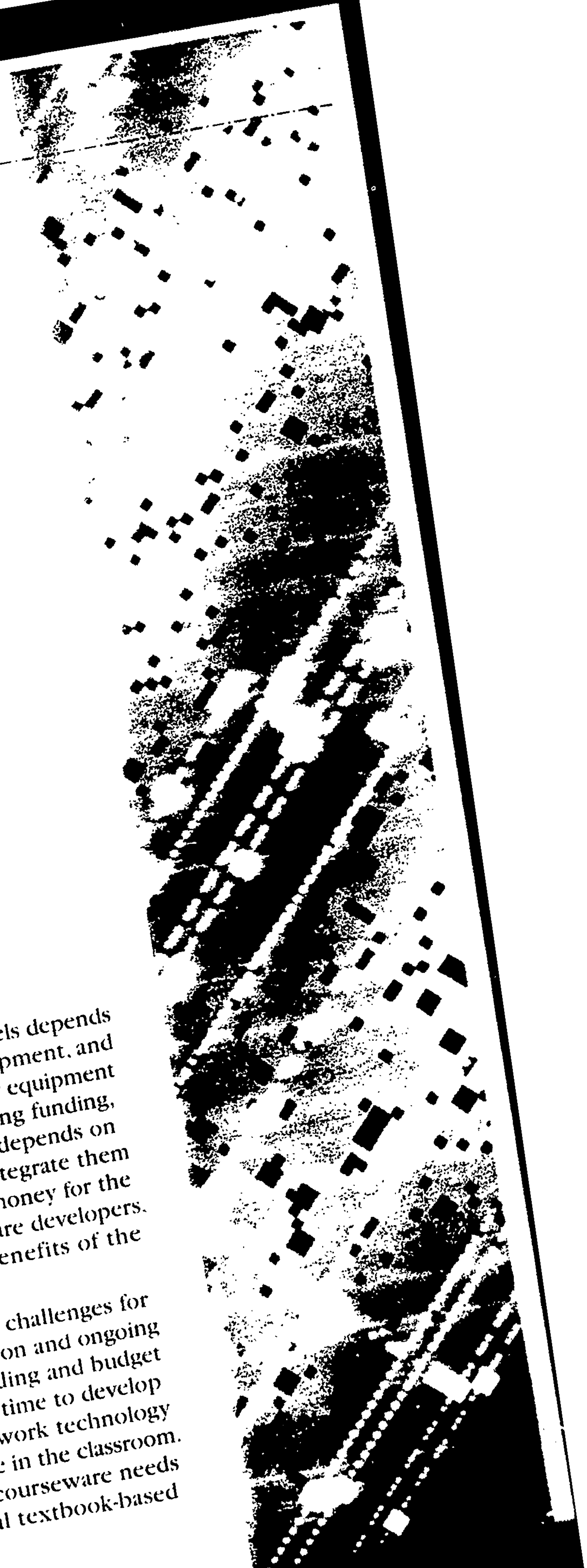
CHALLENGES TO CAPTURING THE BENEFITS



The pace of deployment for any of these infrastructure models depends on three factors: funding availability, professional development, and courseware availability. Schools' ability to acquire computer equipment and network their facilities is primarily a matter of obtaining funding, but the value of the hardware and network connections depends on the quality of the applications and teachers' ability to integrate them into the curriculum. In other words, simply raising the money for the physical infrastructure is not enough: teachers, courseware developers, and community leaders must come together if the benefits of the infrastructure are to be realized.

Consequently, deployment presents a number of challenges for schools. First, districts need to raise funds for installation and ongoing operations in the face of competing demands for funding and budget cutbacks. Second, teachers need both incentives and time to develop the new skills required to make effective use of network technology through both formal training and hands-on experience in the classroom. Third, a wide selection of high-quality multimedia courseware needs to be made available to supplement the traditional textbook-based curriculum.

These challenges increase as schools progress from the relatively simple goal of promoting computer literacy to more ambitious efforts to use network technology as an integral part of the curriculum. While a lab may be sufficient for basic computer-based assignments, networked computers need to be in the classroom if they are to be used as part of the day-to-day learning experience. Broad deployment, in turn, raises the funding hurdle and puts much greater demands on teachers. A broader selection of courseware is also required to meet the needs of a wide range of subjects and grades.

Although these challenges are substantial, they are surmountable. Funding needs can be met by a combination of reducing costs, reprogramming existing educational funds, and obtaining funds from new sources. Teachers' skills will develop with appropriate incentives, on-the-job experience, and in-service training; revised certification requirements and teacher college curriculums will also help reinforce this goal. Finally, the courseware market will develop as demand mounts from schools that have deployed the infrastructure and teachers search for new on-line content.

Meeting the funding challenge

The funding challenge is substantial both because of the limited access most schools have today to the basic infrastructure, and because of the fiscal pressures at work in the current budgetary environment. Setting budget priorities among many competing demands for funds—and securing grants, donations, and subsidies—requires strong leadership at many levels and a clear, compelling vision, as well as a good dose of creativity and persistence.

Limited current infrastructure. When it comes to basic infrastructure, most schools are starting from a low base. While many schools have computers, as of 1994 over 85% of these computers were not equipped to support the latest multimedia courseware—in other words, they could not combine text with advanced graphics, video or sound. Neither could many connect to an internal or external network. Factoring in new computer purchases in the 1994-95 school year, there are now on average 14 multimedia-capable computers per K-12 school or approximately 38 students per multimedia-capable computer. However, averages are misleading: the computers are not evenly distributed across schools. Surveys conducted by Quality Education Data, Inc., reveal disparities across schools based on socioeconomic and racial/ethnic status, although the situation has been corrected to some extent through federal funds and special grants available to underprivileged areas. For example, public K-12 schools with less than 20% of students qualifying for Chapter 1 funds (i.e., students from low income families) average nearly 8.6 computers (of any type) per 100 students while schools with over 80% average only 7.2 computers per 100

students. Likewise, schools with no minority students average 9.9 computers per 100 students while schools with over 90 percent minority students average only 7.3 computers per 100 students.[27]

Similarly, the external and internal network connections in schools today are limited. While 49% of schools have local area networks, half of those connect administrative computers. Fewer than 10% of these networks connected computers in all classrooms as of the 1993-1994 school year.[28] Likewise, although most schools have telephone lines, almost all are for administrative use; only 12% of classrooms have telephones.[29] Fewer than 5% of schools have high-speed, high-quality ISDN or T-1 connections,[30] and rough estimates from telephone companies indicate that up to one-third of schools are in areas where ISDN and T-1 connections are currently not available. Furthermore, while over 70% of schools have cable installed and up to 35% have satellite hook-ups, little of this infrastructure is currently capable of handling interactive applications.[31]

Budget pressures. To place the funding discussion in context, about 1.3% of the national public school budget is currently spent on instructional technology.[32] As discussed above, current spending would almost cover nationwide deployment of the Lab model, which would consume at most 1.5% of the nation's annual education budget. (This is a nationwide average; as mentioned above, the percentage of an individual school's budget going to technology would vary.) The Classroom model, on the other hand, poses a much greater challenge: the instructional technology budget would need to triple to meet the 3.9% of spending that this model would require. However, a continuation through 2005 of the recent technology spending growth rate of 16.5% per year would come close to reaching that 3.9% level—if this growth rate can be sustained. (See Exhibit 9: "Projected School Instructional Technology Spending.")

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[27] *Technology in Public Schools: QED's 13th Annual Census of Public School Technology Use* (Denver, Colorado: Quality Education Data, Inc., 1994), pp. 26-27.

[28] Market Data Retrieval reports that, during the 1992-1993 school year, 49% of schools had a local area network for any use; see *K-12 Education Market Report* (Washington, D.C.: Software Publishers Association, July 1994), p. 31. QED reports for the 1993-1994 school year that 23% of schools had a network for instructional use, of which 18% (or 4% of all schools) connected classrooms; see *Technology in Public Schools*, supra note 27, pp. 76-77; see also *Educational Technology Trends, QED's 7th Annual Sample Survey of Technology Use and Purchase Plans in U.S. Public Schools* (Denver, Colorado: Quality Education Data, Inc., 1994), p. 56.

[29] Princeton Survey Research Associates, "National Education Association Communications Survey: Report of the Findings" (Washington, D.C.: National Education Association, 1993), p. 2.

[30] National Center for Education Statistics (NCES), *Advanced Telecommunications in U.S. Public Schools, K-12* (Washington, D.C.: U.S. Department of Education, Office of Educational Research and Improvement, February 1995), p. 13. Of the 49% of schools reporting wide-area network access, 3% report having a T-1 connection, and 4% an ISDN connection, suggesting that 3.5% of all schools have access to either one. In addition, 4% of the 49% reported access to "other" connections.

[31] Ibid., p. 7; Margaret Honey and Andres Henriquez, *Telecommunications and K-12 Educators: Findings from a National Survey* (New York: Center for Technology in Education, Bank Street College of Education, 1993), p. 11.

[32] See Appendix C for the breakdown and derivation of this figure.

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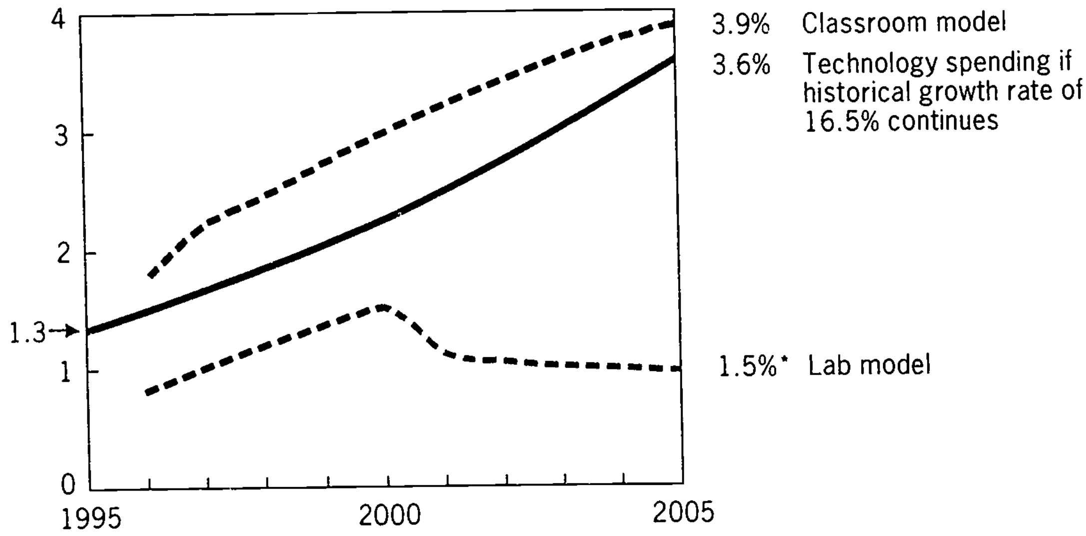
Exhibit 9

PROJECTED SCHOOL INSTRUCTIONAL TECHNOLOGY SPENDING

Percent of public K-12 spending



* In 2000, final year of deployment

Source: National Center for Education Statistics; Software Publishers Association; McKinsey analysis

Sustaining such a growth rate, however, will not be easy. The education budget is caught between upward pressures on spending due to demographics, inflation, and other demands, and downward fiscal pressures on government spending programs. The $249 billion per year that is currently spent overall on public K-12 education is forecasted to grow at a rate of 5.6% per year through 2005. About 1% of this increase comes from predicted growth in the number of students, and 3% from inflation, leaving only 1.6% for all other increases in per-student spending.[33] And given mounting pressures for cuts in federal, state and local budgets, this projected 5.6% growth rate may not materialize, further constraining technology spending.

Other important demands for educational funds also will compete with technology for share of the budget. Basic repairs and facilities upgrades (estimated at $101 billion) are a top priority for many schools, as are school security programs.[34] Mandated programs, such as compliance with federal requirements for asbestos removal and handicapped access ($11 billion over the next 3 years) are also contributing to budget

[33] National Center for Education Statistics, *Projections of Education Statistics to 2005* (Washington, D.C., U.S. Department of Education, Office of Educational Research and Improvement, January 1995), p. 83.

[34] Not all repair and upgrade expenditures are inconsistent with technology spending however In fact, retrofitting schools to accommodate technology can be effectively coordinated with some repairs and upgrades. See Ezra D. Ehrenkrantz, "Retrofitting in Increments, Redesigning Your School for Whatever the Future May Bring." *Electronic Learning* (February 1995), pp. 22-23

Exhibit 10

ESTIMATED POTENTIAL FROM COST REDUCTIONS

CLASSROOM MODEL

Element of Infrastructure	Major cost-saving mechanisms	Potential reduction in element cost Percent	Potential contribution to funding challenge Percent of public K-12 spending
Connection to school	• Special rates/subsidies • Volume purchasing by states • Share cost with other government agencies	5-50 10-60 ?	0.05
Connection within school	• Use of volunteers to pull cable • Volume discounts	10 10	0.05
Hardware	• Purchasing cooperatives at county or state level	5	0.05
Content	• Negotiated discounts in purchase price and alternative licensing agreements • Cooperative ventures with courseware developers • In-house curriculum development	10 ?	0.05
Professional development	• Extensive peer training and support • Vendor-provided training and support	5-40	0.20
Systems operation	• Wide availability of best practices and "how-to" materials and sources • One-time repair contracts • Vendor-provided integration/operation	2	~0.00
	Total potential contribution	**10%**	**~0.40%**

Source: Interviews; McKinsey analysis

pressures.[35] Finally, teachers' salaries—currently 57% of educational spending—have increased faster than inflation over the past decade.[36] Technology requires funding not just for the initial installation, but also for ongoing operations, training, upgrade and maintenance costs. Locking sufficient funds into the budget over the long term implies that these budget battles will need to be fought year after year.

Despite these budgetary pressures, our analysis suggests that the funding challenge can be met through a combination of cost reduction, reprogramming existing funds, and additional initiatives from both private and public sectors. For example, the Classroom model could

[35] U.S. General Accounting Office, *School Facilities: Condition of America's Schools* (Washington, D.C., February 1995), pp. 5-7

[36] From 1980 to 1993, teacher pay increased relative to inflation (20% higher). "Will Schools Ever Get Better?" *Business Week*, April 17, 1995.

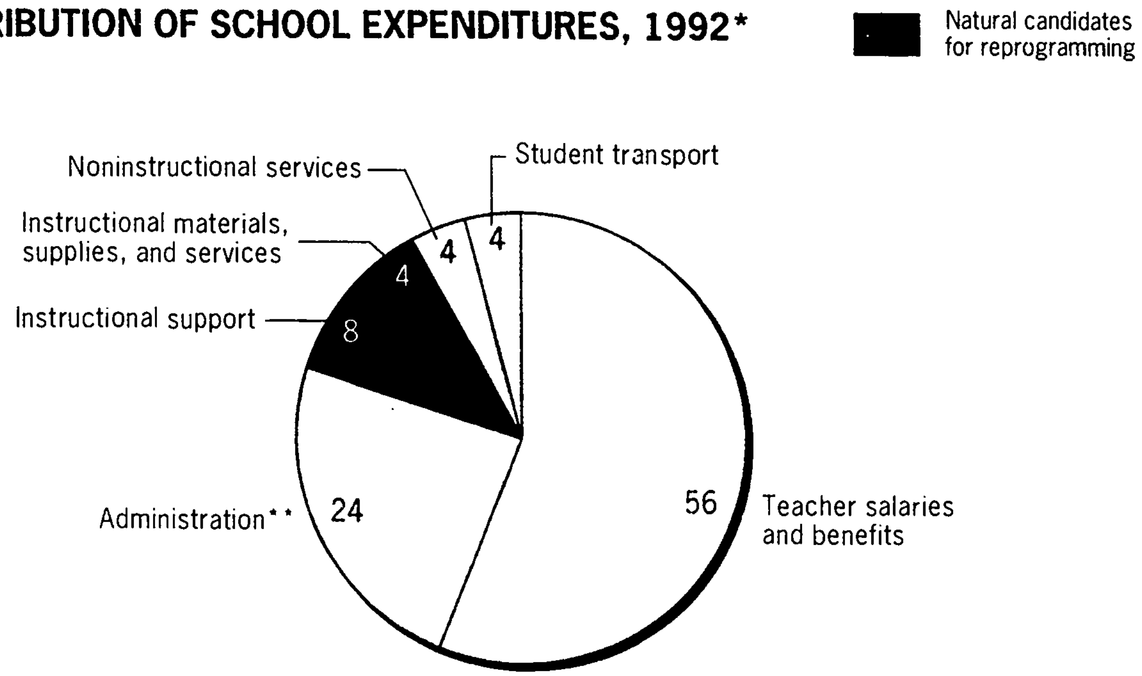
be funded by the following combination of initiatives: maintaining the current spending rate on technology of 1.3%, capturing 0.4% through additional cost reductions (or a further 10% savings on purchases), reprogramming anywhere from 1% to 2% of closely related budget categories, and securing up to 1% in additional funds. The more successful the cost reduction and reprogramming initiatives are, the lighter the burden that will fall on securing alternative funds. The following list of funding suggestions is neither prescriptive nor by any means exhaustive.

Reduce costs. One way to reduce the cost of deployment is to form buying consortiums at the state, regional, or national level to negotiate lower prices than a typical district could negotiate on its own. Such negotiation with equipment and service providers could reduce the cost of deploying the Classroom model by about 10%: these savings go beyond discounts assumed in the model. (See Exhibit 10: "Estimated Potential from Cost Reductions.") Likewise, securing donations of in-kind services from local community groups—free local area network installation, for example—represents another way to reduce individual schools' funding burden.

Cost reduction efforts should target the largest cost elements that can be affected: hardware, internal network installation, and professional development for teachers. Most proposals to date, however, have

Exhibit 11

DISTRIBUTION OF SCHOOL EXPENDITURES, 1992*
Percent



* Based on California, Texas, New York, and Illinois
** Includes General Administration 3%, School Administration 8%, Operations and Maintenance 10%, and other support 3%

Source: National Center for Education Statistics

Exhibit 12

ESTIMATED POTENTIAL FROM REPROGRAMMING FUNDS*

CLASSROOM MODEL

Budget category	Assumption	Potential contribution to funding challenge Percent of public K-12 spending
Instructional material	Shift print materials to software	0.8 - 1.3
Instructional support	Shift part of job focus to selecting software/integrating technology	0.2 - 0.5
Discretionary spending on field trips, supplies	Shift to virtual field trips and technology supplies	0.1 - 0.4
Vocational training	Incorporate technology purchases (e.g., computer lab in favor of wood shop)	?
	Total potential contribution*	**1.1% - 2.2%+**

* Does not include reprogramming funds from "unrelated" spending categories (e.g., streamlining administrative expense to pay for technology)

Source: National Center for Education Statistics; Interviews; McKinsey analysis

focused on the connection to the school—for example, ensuring universal access to the Internet through telephone line or other connections. While such initiatives are important, they will not by themselves make much of a dent in overall funding needs.

Reprogram existing funds. A second set of actions focuses on shifting existing educational funds to new uses. Selected categories of the school budget are natural candidates for potential reprogramming in support of connecting schools (see Exhibit 11: "Distribution of School Expenditures, 1992"). Textbooks account for about half of schools' expenditures on "instructional materials, supplies, and services"—about 2% of total school spending. Some of these funds could be used for multimedia courseware and on-line instructional materials, supplementing (or replacing) traditional textbook purchases. Another 8% of school spending is currently devoted to "instructional support," such as instructional supervisors (e.g., the head of the math department). Some of these resources could be redeployed to address teacher training and support needs. For example, instructional supervisors could focus on helping teachers integrate technology-based tools into the curriculum.

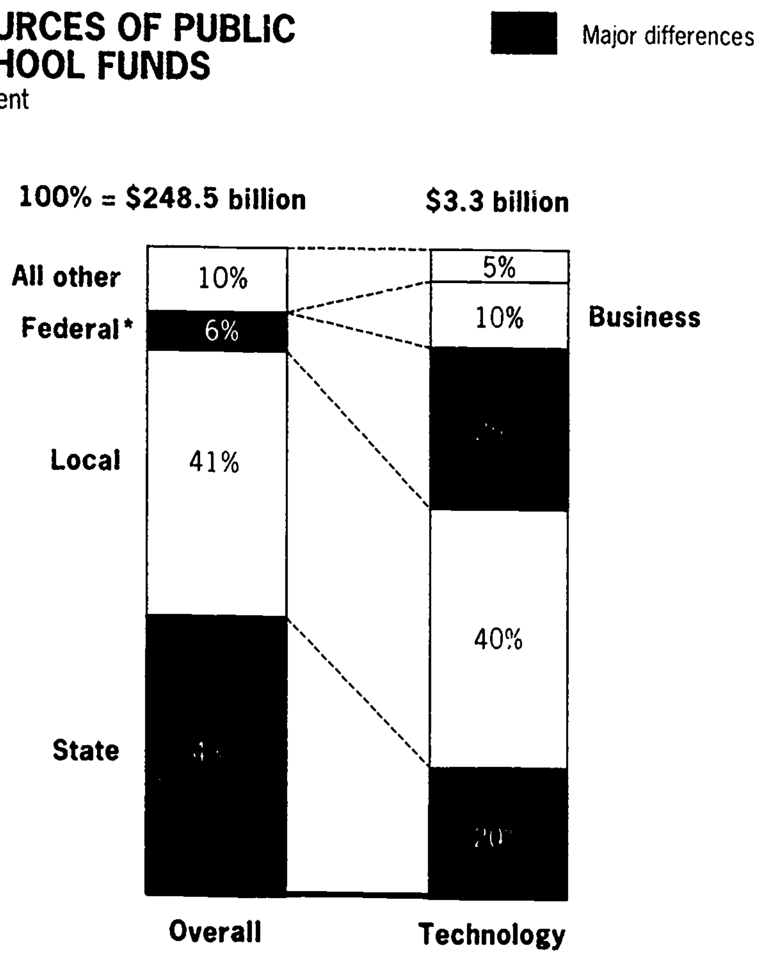
Reprogramming funds within these natural candidate categories could contribute 1% to 2% to the technology budget (see Exhibit 12, previous page: "Estimated Potential from Reprogramming Funds"). In addition to this 1% to 2% from natural candidates, some general funding categories can also be reprogrammed. In Carrollton, Georgia, for instance, the district cut administrative staff by 20% to 30%, releasing funds for technology and connection within their schools. Some schools, such as those in the Hueneme District, have chosen to fund technology rather that teachers' aides.

Secure additional funds. A third funding option—and perhaps the most difficult—is to secure new sources of funding. Currently, state and local government funds cover 84% of the public K-12 education budget, but account directly for only 60% of technology spending (see Exhibit 13: "Sources of Public School Funds"). Some state and local governments have issued special educational bonds, increased taxes, and/or allocated lottery funds to cover investment in educational technology. A range of other funding sources have provided support for technology to date, including federal Chapter 1 and 2 funds.

Innovative schools and districts have also found a number of ways to raise money from local community groups, private industry, and foundations. Some schools and districts have been fortunate enough to be chosen as model schools or pilot sites for major equipment suppliers including telephone, cable, and computer companies. Others have received special grants from a range of sources, including private foundations. Some have set up entrepreneurial ventures such as developing and selling their own educational software. The Carrollton School District offers one good example of a creative approach to funding. (See sidebar, "Case Study: Carrollton School District, Georgia.")

Exhibit 13

SOURCES OF PUBLIC SCHOOL FUNDS
Percent



* Includes Title 1/Chapter1; Title 6/Chapter 2; Job Training Partnership Act; bilingual and other programs

Source: U.S. Department of Education; Software Publishers Association; Education Turnkey Systems; CCA Consulting

CASE STUDY

CARROLLTON SCHOOL DISTRICT GEORGIA

In the last 4 years, leaders of the Carrollton City School District have attracted tremendous funding and technical support for their plans to introduce technology into the school system. Telecommunications, Inc. (TCI) has contributed in excess of $1 million; IBM and the IBM Foundation have contributed nearly $1 million; local businesses such as Southwire Company, Citizens Bank and Trust, Georgia Power, Southern Bell, Sony Music, Inc., and Peachtree Cable, Inc. have provided grants of $500 to $50,000 and helped to train teachers. The state of Georgia has contributed a grant of $820,000 from a part of the Universal Service Fund created by Senate Bill 144, which took Southern Bell overcharges that would normally be refunded in small checks to consumers and created a $50 million fund to build a telecommunications infrastructure for medicine and education in Georgia.

How did the Carrollton City School District leadership attract all the support? Not by demonstrating a need any more acute than its fellow districts in the state. With three schools and 3,504 K-12 students, the Carrollton City School District looks pretty average from a purely statistical point of view. But the district leadership is light-years ahead of many when it comes to choosing a direction, galvanizing support for its goal, and finding ways to secure funding.

In 1984, school district administrators decided to get the entire community involved in determining the direction of education in Carrollton City. Since then, more than 300 members of the community have participated in articulating a vision for education, including a vision to create a community network that connects West Georgia College, libraries, Tanner Medical Center, county agencies, private homes, and the school system. To turn that vision into reality, the district initiated a series of events to market the vision to the full community and build support and momentum for it.

It invited prominent leaders from local government, business, the clergy, and education to talk about the district's vision for networking and how to finance it. Clear support from the city council, the mayor, the school board, and business followed. TCI identified Carrollton High School as its first National Showcase School and provided a video headend and cable to all school sites. IBM loaned every teacher a computer for a year and helped arrange long-term financing for a building-wide network that included eight file servers and 275 computer work stations, seven in every classroom. The district even got voters to approve a bond issuance to build a new school with all the state-of-the-art technology in place and, by redefining classrooms as "academic labs," was able to increase state funding by 20 percent.

But beyond the joint problem solving and funding that followed, the district has achieved an important intangible that will help it maintain the system–currently a $600,000-a-year proposition. The high level of community involvement has created commitment to a shared vision of education and accountability outside the school and administration walls. This awareness continues to inspire creative ways of funding the system. (One idea currently under consideration, for example, is to sell file server access to the local cable company, which would then resell the access to households.)

With a decrease in the drop-out rate from 19 percent to just under 5 percent in 5 years, it appears that the community's efforts to create a more active and engaging learning environment through technology are paying off. The Carrollton City School District leadership and the community should feel encouraged that together they are taking the district in the right direction.

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Providing professional development

As discussed above, the greatest benefit from connecting schools to the information superhighway is derived when the technology is fully integrated into the curriculum. Integration into the curriculum requires that teachers be able to use the technology effectively in whatever subject they are instructing. In turn, this requires professional development for the vast majority of teachers: first, to master the technology; second, to learn new teaching methods incorporating the technology. In addition, it requires professional development for those who advise and support teachers: school librarians, media specialists, and administrators.

According to Teaching Matters, a New York-based education consulting firm,[37] almost 50% of teachers have little or no experience with the relevant technology. The current system does little to support teachers in acquiring these skills. Few teachers have full-time access to a computer at school. In addition, there is little opportunity or incentive to gain pre-service training in technology. Only 18 states include any technology skills among the requirements for teacher credentialing. And in most states, the requirements are too low to matter. Most schools and colleges of education have relatively little technical equipment or resources, and they devote limited course time to preparing teachers to use technology effectively in the classroom. In California, for example, a year-long teacher training program includes a total of only 11 hours instruction on the use of computers and little or no instruction on networking or other aspects of the NII.

In-service professional development opportunities offered or required by schools and districts vary widely, but generally tend to be minimal. QED reports that 81% of school districts spend less than 10% of their technology budgets on training.[38] Based on a survey of its readers—who are likely to be relatively sophisticated technology users—*Electronic Learning* reports that only 8% of technology budgets went to training.[39] While these numbers are likely to understate training and support, they are consistent with our own case studies and interviews, which indicate that even most "model" technology schools spend no more than 15% on training and support. By contrast, the "Teacher Skill Stages" model (to be discussed below) calls for substantially greater expenditures. Experience in the corporate sector shows that investment in training is crucial to getting the benefits out of technology. Likewise, teachers, as well as corporate employees, need to learn both how to use the technology and how to do their jobs differently.

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[37] Teaching Matters, Inc., a not-for-profit organization, has worked extensively with K-12 schools in and around New York City to develop, monitor, and deliver professional development programs (formal training plus ongoing support) which help teachers and principals to integrate technology into their classrooms.

[38] *Educational Technology Trends*, supra note 28, p. 11.

[39] Jessica Siegel, "The State of Teacher Training: The Results of the First National Survey of Technology Staff Development in Schools," *Electronic Learning* (May/June 1995), p. 44

Most of the in-service training in technology skills that teachers do receive is at best exposure rather than real skill building. *Electronic Learning* found that only 21% of training courses are geared toward integrating technology into the curriculum.[10] In addition, half of all training is delivered in the form of a half-day workshop.[11] A lecture or half-day seminar with little or no follow-up or in-classroom support is unlikely to promote either mastery of the technology or changes in teaching approaches to incorporate the technology.

Finally, teachers have little incentive to pursue aggressively the type of professional development needed to integrate technology into the curriculum. Districts that tie pay scales or recertification to continuing education rarely mandate a technology component. Furthermore, most college entrance requirements do not address technology competence or the use of technology in exploring academic subject areas. Consequently, there is little motivation for K-12 teachers to regard technology as playing an essential role in preparing their students for college.

Nonetheless, we have observed many teachers taking the initiative to learn and use computers and the NII in their teaching. And, of course, we found a few districts where teachers were given the lead role and the time and support needed to master the technology and integrate it into their curricula. "We gave six teachers a full year to think through the technology and connectivity they wanted, the physical layout of the classrooms, and the ways in which they integrated technology into their courses," explained Dr. Ron Rescigno, District Superintendent of the Hueneme School District. "They were encouraged to attend conferences and to network with other teachers and professionals associated with technology. Obviously, we still provide real-time support to our teachers and special technology courses on an ongoing basis, but the ability of these six teachers to completely focus on creating their own technology environments has made a huge difference. Talk to any one of those teachers or their students—they are delighted with the outcome."

Another model is offered by the Ontario-Montclair school district, the second largest K-8 district in California, where a large portion of the teacher training occurs in a computer training lab maintained at the district headquarters. Dick Archibald-Woodward, the technology coordinator for the district, believes strongly that teachers require instruction in how to integrate technology into the curriculum, as well as in developing basic computing skills.

The district computer training lab, which Archibald-Woodward manages, has about 30 computers, including Apple IIes, multimedia-capable Macs, and PCs. The instructors are 12 teacher/mentors who add this responsibility to their normal teaching load but are given a supplementary salary stipend. Approximately 400-500 teachers undergo some type of technology training in this center each year. The training programs

[10] Ibid.

[11] Ibid., p. 48.

cover a wide range of topics, including basic computing skills, specific applications, curriculum integration, and networking. Teachers can receive college credit for some of the courses. Some of the training is compensated through regularly scheduled teacher in-service days and release-time training. The district's training program also includes a number of training courses and seminars provided at school sites, as well as support staff who are available to visit sites and provide "just-in-time" training and support as needed.

An interesting twist on teacher professional development is made possible by the technology and connectivity itself. For example, the "Online Internet Institute" is a newly formed initiative that is leveraging the Internet to bring together a group of 665 educators from school districts around the country during the 1995-1996 school year. These educators receive instruction on-line about integrating the Internet within their classrooms and supporting their peers in doing the same. This instruction is provided by on-line mentors and includes access to information resources and support for curriculum integration (e.g., lesson plans, technology suggestions).[12]

In addition to in-service development opportunities, some states and colleges of education are taking the lead in establishing higher standards of competency with technology and providing the resources—including equipment, course time, and expertise—to ensure better preparation of teachers entering the school system. For example, the School of Education at Northwestern Kentucky University is actively working on increasing the requirements for technology training beyond a one or three semester hour course. The School is investing in new technology infrastructure both for its computer lab and in support of its computer-aided classes, in which each student is provided a computer and modem for the semester. Most of this activity anticipates the implementation of a state-wide technology plan for the K-12 public school system.[13]

In Texas, the Houston Consortium is focusing on completely redesigning teacher education. The Consortium's effort to integrate technology into the pre-service education of teachers is particularly significant. Each prospective teacher is encouraged to purchase a laptop computer for lesson planning, telecommunications, record keeping, and instruction. The Consortium also supplies each participating K-12 school a telecommunications center and a portable multimedia station to be used by the pre-service (and in-service) teachers. Finally, the Consortium also provides both individual laptop computers for the professional development of up to 6 faculty members and a computer classroom (5 computers for instruction and 10 laptops for students) to each participating university or college of education. Training is provided

[12] Interviews with Bonnie Bracey, cofounder of the Institute, September 1995

[13] Connie Carroll Widmer and Valeria Amburgey, "Meeting Technology Guidelines for Teacher Preparation," *Journal of Computing in Teacher Education*, vol. 10, no. 2, pp. 12-17

Exhibit 14

TECHNOLOGY SKILL STAGES FOR TEACHERS

Skill stage	Description	Professional development needed
Entry	Teachers struggle to cope with technology and new learning environment, or have no experience at all	—
Adoption	Teacher moves from initial struggle to successful use of technology at a basic level (e.g., can use drill and practice software)	• 30 hours training
Adaptation	Teacher moves from basic use to discovery of potential in a variety of applications. Teacher has good operational knowledge of hardware and can perform basic troubleshooting	• 45+ hours training • 3 months experience • Just-in-time support
Appropriation	Teacher has mastery over the technology and can use it to accomplish a variety of instructional and classroom management goals. Teacher has strong knowledge of hardware, local area networks, and wide-area networks	• 60+ hours training • 2 years experience • Just-in-time support
Invention	Teacher actively develops entirely new learning techniques that utilize technology as a flexible tool	• 80+ hours training • 4-5 years experience • Just-in-time support

Note: Required times are cumulative

Source: U.S. Congress, Office of Technology Assessment; Teaching Matters

both in the use of the technology and in the integration of the technology into the curriculum. To date, the results have been extremely encouraging, and the organizers and participants continue to pursue multiple initiatives in order to make sure that "graduates from the programs of the participating colleges of education will enter the classroom as new teachers with knowledge and skills in the use of technology that will match their knowledge of subject matter and their skills in teaching children."[11]

As examples like these suggest, no one model for teacher professional development will be right for all schools, districts, and states. However, we believe that some basic principles will help many schools get started and some broader actions could provide valuable support to local school and district initiatives.

A first step is to set accurate expectations as to how long effective professional development is likely to take. Exhibit 14, "Technology Skill

[11] Richard Alan Smith, W. Robert Houson, and Bernard Robin, "Preparing Preservice Teachers to Use Technology in the Classroom," *The Computing Teacher* (December/January 1994-1995), p. 59.

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Stages for Teachers," shows a five-stage professional development model based on our analysis, with input from Teaching Matters. Moving teachers from entry through the first two stages could be achieved in half a school year for any one teacher. The prerequisites are adequate access to a computer, courseware to enable the use of technology in the curriculum, and support for the teacher in the classroom. Ideally, the support would come both from experts in the technology and from peer teachers. This implies giving teachers time and encouragement to share experiences with each other.

Experience at schools that have been down this path suggests that the two more advanced stages on the professional development model simply take time—from two to five years of real teaching experience with the technology. In addition, progressing to these stages requires encouragement and incentives for teachers to make the extra effort needed to build their own skills and support other teachers. Thus, a school district that starts now with basic "Adoption" and "Adaptation" training could build a population of appropriately skilled teachers over a six- to seven-year period (assuming two years to move all teachers through the basic training—an aggressive assumption, to be sure).

In the meantime, we believe several actions are appropriate for most schools and districts to consider:

- Give teachers, school librarians, and media specialists access to the technology as soon as possible (school librarians and media specialists are often early adopters and supporters of technology). One of the benefits of the Lab Plus model described above is that it provides a computer for each teacher, school librarian, and media specialist.
- Encourage teacher-led initiatives.
- Create incentives—examine credentialing and pay scales to see if direct incentives can be instituted.
- Beyond basic adoption skills, create training programs that use the technology in support of other skill building objectives (e.g., improving critical thinking, implementing new curricula).
- Examine the 1.8% to 5.7% of the budget that districts currently spend on professional development[45] to make sure it devotes the appropriate emphasis to technology skills.
- Allow teachers, school librarians, and media specialists time to share their experiences and provide some in-class support to one another.
- Set goals for moving the entire population of teachers across the five skill stages.

[45] Consortium for Policy Research in Education, *CPRE Policy Briefs* (June 16, 1995).

Beyond the school and district levels, a number of actions could stimulate professional development of teachers. National leaders should:

- Encourage schools of education to integrate technology into their curricula more fully. However, because only 4% of teachers are newly accredited each year and 25% of these stop teaching within two years, the impact will be slow to be felt—but important nonetheless in setting standards and expectations.
- Encourage schools of education and foundations to fund and monitor experiments to identify effective techniques for the use of technology in K-12 education and for the professional development of teachers and other school professionals.
- Encourage continuing education programs for teachers, school librarians, and media specialists to include courses on effective educational uses of technology.
- Examine the $615 million per year (FY1993) the federal government spends on teacher development in science, math, and technology to make sure that this funding gives proper emphasis to the use of computer and network technology in the classroom.[16]

An aggressive professional development effort involving the support of teachers, administrators, boards of education, states, the federal government, and schools of education will be an essential part of effectively connecting students to the NII.

Ensuring courseware availability

Today, the market for courseware is relatively small, fragmented, expensive to enter, and risky. As a consequence, it is underdeveloped—although this will change as K-12 school demand for courseware grows.

For purposes of this discussion, we have defined courseware as "electronic curricular materials." Courseware includes interactive multimedia software, on-line educational services, teacher's guides, and other materials linked directly to prescribed curriculum. The link to curriculum is critical because teachers have a limited time to cover concepts and facts outlined in the curriculum. Good courseware allows students to work in groups and at their own pace, and to receive quick feedback on their progress.

For production of high-quality courseware to flourish, the courseware market needs to expand and to become more attractive and accessible both to existing and to new providers. Fortunately, as more schools commit to connecting to the information superhighway and find the funding to do so, and as more teachers become knowledgeable and excited about using technology in their classes, demand for courseware will naturally grow. Even so, it might be worthwhile to consider options

[16] Ibid.

for stimulating growth in the courseware industry—for example, speeding up the schools' slow and bureaucratic procurement processes—to make sure that enough good courseware is available to encourage schools and teachers to experiment with technology in the near term.

Small, fragmented market. Just a piece of the overall education market, courseware comes in two basic types: (1) integrated programs that typically support a full-year course, and (2) more tightly focused, modular programs that cover a specific topic (e.g., the Oregon Trail, the writing of the Constitution). The market for both types of courseware totaled about $290 million in 1993-1994.[47]

At $290 million, the courseware market is smaller than other software markets. One particularly relevant comparison is to the home market for educational applications, since developers who have chosen to focus on the education market have told us that the home market is most attractive. LINK Resources estimates the size of the home education software market at $1.4 billion in 1995, and the home "edutainment" market at nearly $500 million.[48] Not only does this substantially exceed the size of the K-12 school market, but it is expected to grow at a more rapid pace over the next several years. The growth in the home market is supported by the increasing penetration of multimedia computers into the home. The number of multimedia computers used for instruction in K-12 schools is projected to grow from about 1.0 million in 1994-1995 to 2.2 million by the 1997-1998 school year,[49] while the number in the home is forecasted to grow from 8.0 million in 1994 to 38.3 million in 1997.[50] If these projections hold, then the number of multimedia computers at home will exceed the number in schools by a factor of 24 to 1 by 1997.

[47] This estimate of the size of the courseware market is based on several sources. As mentioned above, there are two types of courseware: the types are called integrated learning systems, or ILS, and modular, unit-based software.

An ILS is a turnkey package that typically supports a full-year course, comes packaged with student management and testing tools, and sometimes includes hardware. Despite their breadth, ILSs are still considered supplemental to textbooks because they typically lack the depth necessary to completely cover a full-year core curriculum. The Software Publisher's Association estimates the software portion of the ILS market at $170 million for 1993-1994. ILSs of the past often had features which caused them to fall out of favor: proprietary hardware, software that did not work with other packages, and a drill-and-practice orientation. ILSs have given way to what one analyst has termed "networked learning systems."

By contrast, modular, unit-based software focuses on a single topic or concept. The size of the market for unit-based software is not tracked separately from the $360 million that schools spend on non-ILS software, which includes edutainment, reference and on-line software and services. Based on interviews and case studies, we estimate that unit-based software accounts for about one-third of this total, or $120 million.

For information about market size, see *K-12 Education Market Report*, supra note 28. For information on market definition, see the Smith, Barney report on Davidson & Associates, August 3, 1993.

[48] *Consumer PC Market Outlook, 1994-1999* (LINK Resources Corporation, June 1995), Tables 6 & 9. The Software Publisher's Association estimates the size of this market for 1994-1995 at $630 million. Edutainment software combines education with entertainment, often in the form of multimedia games. Edutainment products are typically not curriculum-linked and their educational value varies widely.

[49] The 1997-1998 estimate for multimedia-capable computers assumes that K-12 computer shipments continue to grow at 16% per year.

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The size of the courseware market is further constrained by the distinction made between core and supplemental materials. By rule, state textbook monies typically go to core materials. Because courseware is normally considered supplemental, this reduces the available pool of dollars for courseware purchase.

In addition to its relatively small size, the courseware market is fragmented into numerous small segments. Programs need to be tailored to different academic subjects and to individual grade and skill levels. While multimedia courseware lends itself to interdisciplinary content that could combine subjects, state curricula are not currently written in a fashion that would lead to approval of most courseware for multiple subject areas.

The combination of a small market, fragmentation, and a relatively more attractive home market has created a chicken-or-the-egg dilemma for courseware developers. If the demand for courseware were larger, developers would produce more and better educational products. On the other hand, the limited spectrum of available products inhibits the development of infrastructure and therefore the growth of demand.

High cost to serve. The developers we interviewed regard the educational market as a difficult place to do business because sales and service are complicated and expensive. Schools' purchasing process is slow and arduous. Approvals are required at many levels and each decision maker has a high need for information.

Twenty-two states select course materials through an "adoption" process that poses three hurdles for courseware developers. First, the interval between selection of materials for a given subject and grade is long—often five years or more. While this may be appropriate for textbooks, for which the process was designed, it is less desirable for software, which changes rapidly. Second, the sales process is expensive and risky, particularly for smaller developers. For example, the textbook choices of Texas and California carry significant weight throughout the country. As a result, vendors spend heavily—with no guarantee of success—to lobby the committees of teachers and other stakeholders who recommend materials in these states. After participating in the adoption process in one of these major states, one developer of highly acclaimed courseware said that it could not afford to do so again for many years. Third, the sales cycle does not necessarily end with adoption. In states that select more than one text, adoption merely signals that the next phase of the sales cycle has begun, this one directed to district- and school-level officials.

In addition to the difficulties with the adoption process, the mechanics of school district purchasing practices are often cumbersome. District agents require purchase orders tailored to their own unique systems. Some want to be billed after the goods have been received;

[50] *Consumer PC Market Outlook: 1994-1999*, supra note 48, Table 4.

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others before. Some are restricted from paying until the product has been fully consumed, which is particularly difficult for a product that is part software and part on-line service. Others put off buying until the end of the budget cycle, ordering if they have money left over and requiring delivery within the week. The combined effect of such procurement practices is to raise the costs providers must bear.

The school courseware market is also costly to service due to high training needs. Pioneer providers often face high training costs because teachers are simply not familiar with computers and networks. One developer of a networked application stated that by far the main reason for calls to its help line was that the teacher did not understand how to connect to the network.

Risks of product development. Courseware is relatively expensive to develop and comes with little guarantee of success. The experience of multimedia developers generally is a good illustration of the risks faced by courseware developers specifically. A survey of 912 multimedia software developers conducted by Gistics, a California consulting firm, concluded that 96% were unprofitable.[51]

In addition, multiple platforms further increase the costs of production. The public schools have a mix of Apple Macintoshes, IBM-compatible computers, and older Apple IIe and Commodore machines. While new applications and developers generally aim at the new machines, porting an application developed for the Apple Macintosh Operating System to the Windows operating system can add 10-20% to its cost.

Addressing the courseware challenges. As mentioned above, some of these problems are likely to sort themselves out over time as more schools begin using computers and networks in the classroom, and the market for courseware grows as a result. However, there are steps that could be taken now to stimulate the courseware market in the near term. It is hard to know just how important such steps would be, but they seem to be worth careful consideration.

Perhaps most important, there are a number of ways to address the small size of the courseware market. Clearly stated national goals for deploying technology in the schools, state technology plans, and real appropriations could build confidence among courseware providers that demand will grow and that the growth will be sustained. In addition, changing the rule in many states that prevents textbook money from being spent on courseware would help. Twenty-one of twenty-two adoption states have taken steps in this direction by redefining instructional materials to include electronic content. The next step would be to relax the distinction between core and supplemental materials.

[51] Jim Carlton, "Companies Aim to Dominate Fun Learning," *The Wall Street Journal* (August 2, 1995), p. B1.

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Furthermore, the fragmentation of the market into small segments defined by grade and subject is not inevitable. Instead, wider skill-based, cross-disciplinary segments could evolve. Many districts and states are systematically rethinking and updating their curricula. To the extent that the new curricula emphasize flexibility of method and skills over content, this would encourage the formation of these larger, more profitable market segments.

The high cost to serve the K-12 market can also be addressed. Districts can streamline their purchasing practices. Friendlier adoption rules for courseware can be created. And training and support at the school level can be enhanced so that early developers do not have to bear the brunt of training teachers in computer basics and solving their particular hardware problems.

To mitigate the risks faced by early developers, states and districts can enter into partnerships with developers. Agreements might range from providing venture capital, to cooperative development arrangements, and to advance agreements to purchase. For instance, the state of Florida has established a fund to encourage the development of courseware that meets its curriculum needs. In return for providing seed funding, schools within the state receive a discount on packages purchased. Money earned by the state on its investment is returned to the fund, which has just seen its first product complete the cycle through development to sales to dividends. When the Guilford County School District in North Carolina wanted teacher productivity and student performance management software, it scoured the market but could not find the product that met its needs. So it contracted with McGraw-Hill to build the system; McGraw-Hill was pleased by the deal because it reduced the risks of development.

Grants have also been used to stimulate the development of high-quality courseware. Several challenge grants from the National Science Foundation (NSF) have been focused on courseware or the underlying tools to create it.[52] For instance, The Geometer's Sketchpad allows students to test hypotheses in real time on geometric models they create on the computer. Students can explore the model by manipulating objects and observing how the other objects respond. Students' observations can be visual, or they can measure the resulting angles, lengths, and areas using tools built into the program. The Sketchpad grew out of the Geometry Forum, a project at Swarthmore University funded by the NSF.[53]

[52] Jerry Michalski, *Release 1.0, Esther Dyson's Monthly Report* (New York: EDVenture Holdings, Inc., May 1995), pp. 2 and 5. The report states: "The U.S. National Science Foundation (NSF) has funded many useful projects along these lines. In fact, almost every project we found intriguing was NSF-backed. It seems strange that NSF is the sole funder of so much activity. There's clearly a greater role possible for software developers and corporations."

[53] Ibid., pp. 5-6.

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LEADERSHIP

These challenges—securing funding, ensuring teachers have the skills to integrate applications into the curriculum, and obtaining quality courseware—will set the pace of implementation for many schools. Over time, the market for courseware will develop, teachers will build skills and experience, and determined school districts will find the funds for deployment. As case studies demonstrate, leading-edge schools are already clearing these hurdles, even in relatively poorly funded districts. But facing down competing demands for scarce budget dollars, motivating teachers to make fundamental changes in their approach to teaching, and making creative use of courseware and the Internet, all demand one thing: strong leadership.

And it must be leadership sustained over time. It will take several years, perhaps a decade, for most schools or districts to bring all the necessary elements—infrastructure, funding, professional development, and courseware—into alignment. Through every stage of that deployment period, dedicated leaders will need to provide direction and maintain momentum. This will probably be the single most important factor determining not only the pace of deployment, but also the level of success in capturing the educational benefits of the NII.

Connecting schools to the information superhighway involves a systemic process of change, demanding new styles of teaching and learning and new priorities for funding and resource allocation. To launch and sustain this process, leaders need to provide a compelling vision of success and a sense of urgency, pull together funding from multiple sources, create an environment where teachers can learn and be rewarded for using the technology, and ensure adequate support for both initial deployment and for ongoing operations.

Leadership needs to come at many levels, from both the public and private sectors. There is no "blueprint" for deployment nor single set of national policies that can meet the diverse needs of every school district. For this reason, deployment requires a local, "bottom-up" approach. At the same time, individual schools clearly need top-down help in marshaling the resources to overcome these challenges. In the schools we visited, the district superintendent often has taken the lead role, bringing together community leaders and school boards, teachers and administrators, as well as private industry and government leaders to make change happen.

Local community and school leadership is the most powerful and important source of energy for driving deployment. Without the commitment of teachers, administrators, and parents, little change can happen in the classroom or the school. School boards, superintendents, principals, and other community leaders need to establish a clear vision and agree on concrete goals. They need to redefine teachers' job requirements, reward risk-takers, drum up volunteers to donate services or equipment, secure funding, and guide deployment programs around the snares of the budget and procurement processes.

Some form of public-private partnership lies at the center of many successful community leadership models. In Carrollton, Georgia, for example, active proponents on the school board and senior executives from local businesses drove the deployment process. They helped procure affordable equipment, convinced technical support groups to donate time to run wiring through school facilities, and provided ongoing funding to the school district. At the Dalton School in New York City, parents have supported the effort by endorsing and encouraging the new teaching methods. Columbia University has also provided free connections to its own network and has established a partnership for joint courseware development.

Teachers, too, are critical agents of change. They need to take the initiative to use new teaching techniques and make creative use of the technology. They are the first to encounter the obstacles of inadequate support and courseware, as well as the first to realize the benefits of more engaging learning tools and improved communications. Teachers play a pivotal role in informing, assisting, and coaching their peers, thus building the momentum for change. Innovative

teachers often need to be mavericks, giving their own unpaid time to training and finding ways around bureaucratic obstacles.

However, local school and community leadership is necessary but not sufficient to meet the goal of nationwide connection to the NII. Not all school districts have the ability or desire to make deployment a top priority; no individual school or community alone can stimulate the courseware market or legislate new federal funding. **Leadership at the state and national level**—in both the public and private sectors—is also necessary to help speed deployment and ensure that it is equitable.

Many states are developing technology plans that help prioritize uses of state funds and offer suggestions for funding and infrastructure deployment at the school level. Some states, such as North Carolina, have even justified infrastructure build-outs by combining network requirements across several government functions. As discussed above, federal programs currently provide an important source of technology funding. Government agencies also play an important role simply by endorsing the importance of the NII, communicating "best practices," and advocating key initiatives in public forums.

For example, the President's Office of Science and Technology Policy has assisted Gary Beach, the publisher of *Computerworld*, in creating Tech Corps, a national, non-profit organization of technology volunteers dedicated to helping improve K-12 education at the grass roots level. The mission of Tech Corps is to recruit, place, and support volunteers from the technology community (primarily at state and local levels) who advise and assist schools in the introduction and integration of new technologies into the educational system. An early test of the concept began in Massachusetts in March of this year and involved 12 school districts with over 300 volunteers signed up to assist. Based on this success, the program is now expanding to 40 districts in the state.[51]

In addition, public-private partnerships at the state or national level can complement local efforts and government mandates. Purchasing

[51] Interview with Gary Johnson, Executive Director of Tech Corps, September 1995.

cooperatives, for example, are a powerful way to secure discounts or terms that individual school districts could not negotiate on their own. Private foundations or not-for-profit groups, perhaps with government seed money, can spur courseware development and help publicize successful models for deployment. And, as several of the case studies demonstrate, private industry can have an incentive to fund "experiments," such as Bell Atlantic's involvement with the Christopher Columbus Middle School in Union City, New Jersey, in which Bell Atlantic installed computers at the school and the home of all 7th grade students and teachers, along with local and wide area networks to link them. Private industry partners could also be encouraged to play ongoing roles as deployment progresses.

Finally, educational institutions—especially teacher colleges—have an important role to play in revamping their curricula and providing more robust in-service training support to teachers and other school professionals in light of these new technology training needs. They need to advocate changes in teacher certification requirements and to support courseware development efforts by establishing guidelines and quality standards. They can also sponsor conferences and educational forums, bringing together teachers, administrators, courseware developers, and potential funders.

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There is no magic formula for pulling together the leadership and commitment to change across all these diverse organizations. It is clearly a process, though, that will build on its own momentum. As costs decline, hardware and software evolve, and more teachers become experienced with technology, the perceived risks of deployment will decline. And as more success stories emerge from the growing ranks of innovative schools, documenting the benefits of connection and demonstrating deployment models that work, the enthusiasm and desire to make the change happen will spread from community to community.

APPENDIX A

DETAILS FOR COSTING MODELS FOR CONNECTING SCHOOLS TO THE NII

As discussed in the main body of the report, we constructed several models assuming different levels of infrastructure and timing of deployment to highlight the major cost drivers of technology deployment and the economic breakpoints among deployment options. This appendix is for the reader interested in further detail about cost models.

Costing methodology

For each model, we analyzed the costs associated with six elements of infrastructure: the connection to the school, the connection within the school, hardware, content, professional development, and systems operation. Each of these elements was further broken down into sub-elements. (See Exhibit 15: "Six Elements of Infrastructure.")

We took a three-step approach to estimating the costs for each model. First, we estimated the costs of each of the six infrastructure elements (and sub-elements) for an average school[55] as required by each model. For each element, we estimated the costs of initial deployment as well as ongoing operations and maintenance. Initial deployment costs include the purchase and installation of equipment and first-year operating expenses. Ongoing operations and maintenance costs include usage charges, equipment and content upgrades, and professional development and support. For many elements, we assumed that prices would decline over time. We also made adjustments—based on location and age—to account for major variations in costs from school to school (e.g., the greater cost of deploying computers and local area networks in older schools requiring retrofitting and asbestos removal). Second, we estimated the amount and quality of existing infrastructure for each cost element to determine the true incremental costs of deployment. Third, we scaled the costs up to a national level by multiplying the incremental costs per school by the total number of schools, accounting for the growing student population.[56] For each model, we assumed either a 5 or 10 year deployment period (as noted in Exhibit 4) with the purchase and installation of the equipment evenly spread over that period. All costs are in nominal dollars and assume a 3% inflation rate.

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[55] Averages for 1994-1995 included 5.7 schools per district, 533 students per school, 31 teachers per school, 21 classrooms per school, and 25 students per classroom. These averages are derived from figures provided by the National Center for Education Statistics (NCES).

[56] We utilized the following numbers from the National Center for Education Statistics: 84,500 schools, 14,850 districts, 15.0 million enrolled students, 2.6 million teachers, and 1.8 million instructional rooms. The student population is expected to grow by 7% in 2000 over the 1995 base and by 10% in 2005, according to the Department of Education.

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Exhibit 15

6 ELEMENTS OF INFRASTRUCTURE

Cost drivers by element

	Connection to school	Connection within school	Hardware	Content	Professional development	Systems operation
Purchase/ install	• Bandwidth • Medium (i.e., wireline/ wireless) • Installation	• Bandwidth • Medium • Installation	• Computers and associated equipment (servers, printers) • Installation, (e.g., HVAC, electrical, security) • Video and voice equipment for video and voice models	• Courseware • On-line services/ Internet connection • Tools software • Videotapes	• Initial training for -Teachers -Librarians -Media specialists -Administrators	• Designing • Implementing
Operate/ maintain	• Usage fees • Repairs	• Repairs • Modification	• Repairs • Upgrades • Modification	• Replacements • Upgrades • Usage fees	• Ongoing training and support	• Operating

Our analysis focused primarily on computer-based infrastructure using networked computers as access devices, though costs were also calculated for dedicated video and for telephones and voice mail. As many industry participants have observed, the distinction among computer, video, and voice platforms will blur as broadband connections become more widely available and as computer technology makes its way into televisions and telephones. Someday, interactive television may rival networked computers as a workable base for connecting schools to the NII. We have focused on computer-based technology because it is widely available today and, therefore, provides a sound basis for cost estimates.

Schools may find they have many connection options, depending on where they are located. These options will include both the medium (for example, wireline options include telephone lines and cable; wireless options include satellite, microwave, and cellular) and the type of service (including bandwidth, features and price) offered. For most schools, we assumed telephone company connections because

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they are the most widely available two-way connections and, therefore, best lend themselves to pricing estimates. However, because high-bandwidth telephone company connections are not available in all rural areas (or are very expensive), we based some of our models on wireless radio for a portion of schools in rural areas.[57] While satellite, cable, and other wireless connections offer viable and potentially cost-effective alternatives, today only telephone company connections offer full, two-way interactivity to a significant portion of the country.

For purposes of cost analysis, the telephone company connections considered were POTS and T-1 lines. These two offerings represent a limited set of the available services. Individual schools and districts will want to investigate other wide- and broadband services which may be available from the telephone company—including ISDN, frame relay, and LAN interconnection—as well as non-telephone company options. As discussed in an earlier section of this report, alternate services such as ISDN may prove to be more cost-effective.[58] The answer for a given school will depend on its needs, the available options, and the price of those options, all of which vary widely from area to area.

Computer-based infrastructure options

We modeled the technology infrastructure and costs associated with full connectivity in every classroom of every public K-12 school—the Classroom model. We also analyzed three less ambitious models that could be considered as alternative deployment options or as interim steps on the path to classroom connectivity: a Lab model, a Lab Plus model, and a Partial Classroom model. In addition, we considered a Desktop model (one computer per student) but did not focus our attention there, given its relatively high deployment costs.

These computer-based models and their costs are described in several exhibits throughout this report. The key features of each model are explained in Exhibit 3, "Model Features," and the national level costs displayed in Exhibit 4, "Estimated Cost of Deploying and Operating Infrastructure." Exhibit 16, "Model Costs at National Level," shows the breakdown in national costs by element and model. Finally, Exhibit 17, "Different Representations of Model Costs," displays the costs in three ways: national costs, costs per average school, and costs per enrolled student. The costs of the computer-based models are not incremental to one another; this means, for example, that the Classroom model does not include the Lab model.

[57] Fixed wireless solutions have a number of limitations, particularly in urban or suburban environments: a clear line of sight is required, reliability can be low, only data and digitized video can be transmitted, and there is potential for clogging the bandwidth as more and more users seek to utilize wireless communications

[58] See supra note 26

Exhibit 16

MODEL COSTS AT NATIONAL LEVEL

Computer-based infrastructure
$ Millions

Element	Lab Initial	Lab Ongoing	Lab Plus Initial	Lab Plus Ongoing	Partial Classroom Initial	Partial Classroom Ongoing	Classroom Initial	Classroom Ongoing
Connection to school	815	580	1,345	595	1,715	1,030	1,645	920
Connection within school	1,325	200	1,325	200	5,025	410	6,285	570
Hardware	3,540	660	9,835	1,525	13,740	1,130	23,820	1,950
Content	2,135	1,045	4,775	2,335	3,505	1,715	6,605	2,920
Professional development	2,025	1,215	3,510	2,320	3,665	2,435	6,355	5,675
Systems operation	765	245	960	465	1,220	810	2,110	1,890
Total	**$10,605**	**$3,945**	**$21,750**	**$7,440**	**$28,870**	**$7,530**	**$46,820**	**$13,925**

Exhibit 17

DIFFERENT REPRESENTATIONS OF MODEL COSTS

Computer-based infrastructure

Model	National costs $ Billions Initial	National costs $ Billions Ongoing	Costs per average school $ Thousands Initial	Costs per average school $ Thousands Ongoing	Costs per enrolled student Dollars Initial	Costs per enrolled student Dollars Ongoing
Lab	11	4	125	45	225	80
Lab Plus	22	7	255	85	460	150
Partial Classroom	29	8	340	90	610	155
Classroom	47	14	555	165	965	275

a. Connection to School

External connection costs include installation, access and usage charges for both the school and the district. We assumed mostly wireline connections (primarily POTS lines for the Lab and Lab Plus models and T-1 lines for the Partial Classroom and Classroom models), although costs for some of the rural schools (27%) were estimated with wireless radio. For example, 50% of the rural schools in the Classroom model were assumed to use POTS lines with wireless radio rather than a T-1 line. We used average current Regional Bell Operating Company (RBOC) tariffs as the basis for cost estimates. Tariffs were assumed to decrease by 3% per year through the deployment period.

As discussed in the body of the report (see Meeting the Funding Challenge), current infrastructure for the connection to the school is quite limited; less than 5% have ISDN or T-1 connections and less than 12% of classrooms have telephones.

b. Connection Within School

Internal connection costs include the materials and labor for installing Ethernet LANs (e.g., cabling and network interface cards) as well as file servers, hubs, and routers. File servers are also included for the district.

Our estimates of the LAN costs varied by the age of the school. The NCES estimates that 65% of schools are more than 35 years old and have not undergone a major retrofit. We assumed that physically wiring these schools would require asbestos removal and other retrofitting (for the Partial Classroom and Classroom models). Given the high cost of such remediation, we assumed that wireless LANs were employed where possible, which we estimated to be half of the schools.[59] The cost of installation for wireless LANs is expected to decrease over the next few years to about $200 per node, directly comparable to wireline solutions. For the other half of older buildings, we assumed $63,500 per school for asbestos removal and additional retrofitting. New schools (5%) were assumed to have adequate wiring already built in. Another 30% of schools are between 5 and 35 years old; we assumed these schools neither had wiring nor required asbestos removal.

We assumed a 10 mbps Ethernet LAN that then shifts over time to a 100 mbps LAN at the same cost. The Lab model includes a server at the school ($3,200) and a server at the district ($10,000); the

[59] 2 mbps wireless LANs have been in existence for some time and proven reliable; 10 mbps LANs (Ethernet equivalent) have recently been introduced and early trials are promising. While their relative price makes wireless LANs attractive wherever remediation would be required, many school buildings have structural barriers that make their use impractical.

Classroom model includes 3 servers ($3,200 each) at the school and 2 at the district ($10,000 each).

Based on our review of survey data, we estimate that 7% of classrooms were connected to an Ethernet or comparable LAN in 1994-1995.[60]

c. Hardware

These costs include multimedia-capable computers, printers, scanners, furniture stations, and security systems. They also include any facility upgrades or retrofitting required in older schools, including electricity and HVAC systems, which we estimated could affect up to 23% and 4% of schools respectively. These costs were estimated to be $240,000 for electricity and $31,800 for HVAC in an average school. Obviously, these costs will vary by age and condition of school, as indicated in the body of the report. A computer replacement cycle of 7 years and 5 to 10 year replacement cycles for the other equipment were incorporated into the ongoing operations and maintenance costs.

We assumed multimedia-capable computer prices of $1,700, a typical price paid today by K-12 schools. We further assumed that this price declines by 4% per year. This relatively small price decline is based on the assumption that schools will continue to purchase multimedia-capable computers that have enhanced functionality as it becomes available and that provide special access features for physically impaired students (e.g., written instructions for the hearing impaired, sound for the sight impaired, and special manipulatives for the physically challenged). This viewpoint is validated by the historical trend and is shared by a number of the major hardware manufacturers, who have plans to add functionality and believe that consumers—including those in the schools—will value the upgraded capabilities for at least the timeframe we consider here.

In addition to each computer, we assumed 2 printers ($535 each) and scanners ($675 each) for the Lab model, and 1 printer and scanner per classroom for the Classroom model. Furniture and security equipment were also included ($355 per computer and $350 per room).

We estimated 14 multimedia-capable computers per school today based on installed base statistics and 1994-1995 shipments. (See Exhibit 18: "Instructional Multimedia Computers Per School.") However, these computers are distributed unevenly across schools. We have taken this uneven distribution into account in the Lab model; the adjustment represents approximately a 10% increase in hardware costs. In addition, we assumed an installed base of 1 printer and 3 security/furniture stations per school.

[60] For further discussion on this point, see supra note 28.

Exhibit 18

INSTRUCTIONAL MULTIMEDIA COMPUTERS PER SCHOOL

Thousands

			Instructional	
	Total	Administrative	Non-Multimedia Computer	Multimedia Computer
1993-94 Installed base	5,500	1,265	3,705	530
				6 per school
1994-95 shipments	1,000	230	75	695
				8 per school

Source: QED; Apple; Paul Kagan Associates; CCA Consulting; McKinsey analysis

d. Content

Content costs include prepackaged software and access and usage charges for on-line services. Software upgrades were assumed to be annual or biannual depending on the particular package or service. Ongoing assumptions for software included expenditures for bilingual capability where applicable. While we made specific assumptions about prepackaged software versus services, our belief is that these costs are interchangeable. In total, the expenditure on software for the Lab model in the year 2000 is 30% higher than expenditures on all electronic media today; for the Classroom model, the expenditure in 2005 is 230% higher than today. Future costs were assumed to decrease at 3% per year.

According to NCES data, approximately 35% of schools currently have access to the Internet or commercial on-line services. Once again, however, most of these connections are available only in the school library and/or media center.

e. Professional Development

These costs include substitute teachers (at $100 per day) to cover times when teachers are out for training, as well as support resources—1/4 full-time equivalent (FTE) in the Lab model and 1 1/2 FTE in the Classroom model—shared across the district to help teachers integrate the technology into the curriculum. Costs for the training courses themselves were also included.

In concert with Teaching Matters, we estimated that 50% of the teachers are at the entry level, 25% at adoption, 20% at adaptation, and 5% at appropriation per the stages shown in Exhibit 14: "Teacher Skill Stages." In the Lab model, trainees (teachers, school administrators, librarians, and selected district personnel) receive sufficient instruction to attain basic adoption level (30 hours); in the Classroom model, 80% of teachers are trained to the adaptation level and 20% are trained to a higher level.

f. Systems Operation

Systems operation costs include resources shared across the district dedicated to designing and operating the systems. The initial deployment costs for the Lab and Classroom models are $5,300 for design charges and 1/4 FTE and 1/2 FTE respectively. These same FTEs are assumed on an ongoing basis.

Video Infrastructure

Two video infrastructure models were costed: a business-quality video facility and a low-end professional-quality video facility. These models were costed as incremental to the Classroom (or Partial Classroom) model.

Both models assumed a single video room with a monitor, three cameras, soundproofing material, and microphones. The business-quality facility has a T-1 connection and assumes equipment at a price of approximately $19,000. For 50% of rural schools, we assumed wireless radio with a POTS backchannel (instead of a T-1 connection). The low-end professional-quality facility has a T-3 connection and assumes equipment at a price of approximately $46,000. Telecom charges were based on average RBOC tariffs.

In addition, initial professional development costs were assumed to be $1,775 per school for teachers, and initial and ongoing system operation costs were assumed to be $9,300 and $11,240, respectively, representing a part-time facilitator/system administrator.

Voice Infrastructure

Costs were also estimated for providing voice mail to all schools and for placing telephones in all classrooms. The voice mail costs are independent of the computer-based models, but the classroom telephones assume that classroom wiring is already in place (i.e., the Partial Classroom or Classroom models).

The voice mail option assumes a dedicated voice mail server for each school ($1,500) and the use of one POTS line. Costs for initial training were assumed to be $1,000. No additional allowance was

Exhibit 19

VIDEO AND VOICE INFRASTRUCTURE OPTIONS*

National Costs
$ Millions

Element	Business video		Lower-end professional video		Voicemail and telephones	
	Initial	Ongoing	Initial	Ongoing	Initial	Ongoing
Connection to school	150	0	5,320	2,865	280	245
Connection within school	0	0	0	0	0	0
Hardware	1,155	95	2,785	230	435	25
Content	0	0	0	0	0	0
Professional development	150	0	150	0	0	0
Systems operation	785	950	785	950	85	0
Total	**$2,240**	**$1,045**	**$9,040**	**$4,045**	**$800**	**$270**

* Incremental costs above computer-based infrastructure; thus, some elements are negligible

made for ongoing support; it was assumed this would be handled by dedicated computer support staff.

For the classroom telephone option, 1 telephone per classroom was assumed with 4 telephones per outside line; schools install multiple new POTS lines connected to a concentrator. Once again, costs for professional development and ongoing operations support were assumed to be minimal.

The national costs for video and voice infrastructure by the six elements, are displayed in Exhibit 19.

MODELS AND COST ESTIMATES FROM OTHER STUDIES

APPENDIX B

In addition to this report, we are aware of three studies that estimate the national costs of connecting all public K-12 schools to the NII. We thought it might be helpful for the reader if we briefly summarized the approaches taken by each study and the resulting estimates. The natural tendency would be to directly compare estimates among the studies; however, since each study models different infrastructures, this comparison is difficult. Accordingly, it seems more useful to review the major similarities and differences in approaches and conclusions among each of the studies. We should also note that each study has informed our thinking, and we have appreciated the opportunity to exchange ideas with the authors of the first two studies (the last one is yet to be published). The three studies are:

- *Architecture and Costs of Connecting Schools to the NII* (Lee McKnight and Russell Rothstein, MIT Research Program on Communications Policy, 1995; updating and revising Rothstein, U.S. Department of Education White Paper, 1994)
- *Schools in Cyberspace: The Cost of Providing Broadband Services to Public Schools* (Telecommunications Industries Analysis Project (TIAP), July 1995)
- *Technology in America's Public Schools: Getting It In, Getting It Paid For, and Getting It Used* (not yet published, Milken Institute for Job & Capital Formation, 1995).

MIT/Department of Education

The MIT/Department of Education studies informed our approach early on. The 1995 update (referred to simply as MIT from here on) discusses five models of connectivity which include increasing levels of functionality and expense across all elements of infrastructure.

- MIT's Model 3 ($4 to $10 billion in one-time costs, $1 to $3 billion in ongoing costs) contains many of the same cost elements as our Lab model ($11 billion and $4 billion), though Model 3 distributes the computers among classrooms
- Model 4 ($9 to $22 billion one-time, $2 to $5 billion ongoing) is similar in concept to our Classroom model, though by providing for fewer computers it comes closer in cost to the Partial Classroom model ($29 billion and $8 billion).

Several factors account for the differences between the estimate from the MIT study and this study. First, the costs for each model in

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the MIT work are presented as ranges, while we have estimated a weighted average cost by making assumptions about the distribution of individual costs across schools. For example, within each model the MIT work assumes a single type of connection to the school for all schools, while our approach differentiates between rural and non-rural schools. Second, while the models describe similar levels of infrastructure, they are not identical. Third, the MIT models assume that the current costs for deployment and operation/maintenance remain constant over time, while we have adjusted for declining prices in certain items. Fourth, we have included some initial costs that the MIT researchers have excluded by design—for example, certain software (specifically, packaged applications), furniture stations, printers, and security devices. Finally, we have made different ongoing cost assumptions. Relative to this study, the MIT report assumes less training and support, hardware replacement cycles that are (implicitly) over twice as long, and no packaged software or upgrades.

TIAP

The TIAP study is also similar in approach in that it estimates the costs for three deployment models from the ground up. The TIAP models, for which annual costs are estimated based on five- and twenty-year deployment cycles, are as follows:

- "Teacher-only" ($4 to $6 billion per year over 5 years, and $0.2 to $1.2 billion per year over 20 years)
- "Team of students" ($10 to $12 billion per year over 5 years, and $0.2 to $2.9 billion per year over 20 years)
- "Universal access" ($27 to $31 billion per year over 5 years, and $1 to $9 billion per year over 20 years).

While the TIAP study assumes broadband deployment in all models, it nevertheless concludes that the costs of connection to the school are low relative to the other elements of hard and soft infrastructure (except under a scenario of accelerated broadband deployment coupled with teacher-only access).

In addition to assuming broadband in all models, the TIAP study is different from this report in other respects. First, it does not reduce deployment costs by the currently installed base of computers within the schools. Second, it does not include telecommunications usage charges to the schools: instead, it includes the costs to the Local Exchange Carriers (LECs) of providing broadband service. The TIAP study makes this distinction in order to separate the issues of cost and price for several reasons. First, there is no known tariff for broadband access to schools or any suitable analogous tariffed service. Second, it was conjectured that the costs to provide broadband access to schools might be recovered in ways other than the usual tariffing process.

Milken

The Milken study takes an entirely different approach. Researchers at the Institute surveyed the state education superintendents as to what it would cost to complete their K-12 technology plans. Based on the 40 states that responded to the survey, the Institute projected a cost of $31 billion to "fully implement [each state's] vision for technology." While details of the underlying state technology plans were not available at the time of writing, it appears that the state plans are, on average, less ambitious than the Classroom model outlined in this report. Further, the Milken study seems to have focused on the costs to deploy the infrastructure, not to operate and maintain it.

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APPENDIX C

BREAKDOWN OF CURRENT TECHNOLOGY SPENDING IN PUBLIC K-12 SCHOOLS

We have estimated that 1.3% of the public K-12 educational budget, or $3.3 billion in 1994-1995, is currently spent on technology. This figure includes estimates for each of the six infrastructure elements described in Appendix A. A bottom-up approach to estimating this number is described in Exhibit 20: "Estimating Spending on Public K-12 Instructional Technology."

To cross-check the reasonableness of this estimate, we placed it up against overall spending figures from the Software Publishers Association, Peter Li Education Group, and Anne Wujcik & Associates. In order to make such a comparison, we adjusted their figures to ensure that we were comparing like items. For instance, the Software Publishers Association estimated hardware and software purchases alone at $2.4 billion for 1993-1994[61]—or $2.8 billion for 1994-1995 assuming a 16.5% growth rate. Excluding administrative use, and including expenditures for telecom charges, retrofitting, professional development and systems operation, leads to an estimate of $3.4 billion, or 1.4% of the education budget. The Peter Li Education Group and Anne Wujcik & Associates estimated $2.4 billion in 1994-1995 for instructional technology.[62] Adjusting this figure for retrofitting, professional development, and systems operation leads to $3.2 billion, or 1.3% of the public K-12 budget.

[61] *K-12 Education Market Report*, supra note 28, p. 61.

[62] Peter Li Education Group and Anne Wujcik & Associates, reprinted in ibid., p. 62.

Exhibit 20

ESTIMATED SPENDING ON PUBLIC K-12 INSTRUCTIONAL TECHNOLOGY

$ Billions

Element of Infrastructure	Spending	Comment/rationale
Connection to school	$0.2	• Applied lab model estimate, since current deployment pattern and spending on other elements of infrastructure consistent with that model • Internet and other on-line usage low; distance learning relatively more expensive but not in wide use • This figure should grow faster than overall total over next several years
Connection within school	0.5	• Total hardware spending (LANs and computers) estimated at $1.8 billion (SPA figures adjusted to account for growth and exclude administrative spending) • Add retrofitting and cabling costs, at 15-35% of LAN total—assume low side today
Hardware	1.4	Computers • QED, Apple, Paul Kagan: estimated 600,000 computers to be shipped in 1994-95 for instructional use • SPA/CCA Consulting: estimated 470,000 computers shipped in 1993-94 for instructional use (550,000 with 16% growth) • At $1,700/computer=$0.8 billion to $1.0 billion • Peter Li/Anne Wucjik & Associates estimated at $0.8 billion Retrofitting, security, other hardware (including video), furniture: estimated at 40% of hardware total
Content	0.8	• Software: $0.5 billion (SPA) • Other content conservatively estimated at $0.3 billion (Peter Li & Anne Wucjik, SPA)
Professional development	0.3	Estimated at 10% of total based on case studies, interviews
Systems operation	0.1	Estimated at 5% of total based on case studies, interviews
Total	**$3.3**	**Equals 1.3% of 1994-95 public K-12 spending**

GLOSSARY

Analog: Representing changing values by a variable physical property such as voltage in a circuit or liquid level in a thermometer. As contrasted to *digital* (see below), which represents changing values by binary digits, or *bits*.

Bandwidth: The speed or capacity of a network connection. The more bandwidth a particular medium has, the faster data can be transmitted across it.

Bit: Binary digit, the basic unit of information carried by *digital* systems. transmitted as a single on or off pulse. Bits are grouped together in different sequences to represent all kinds of information—numbers, words, sounds, images, etc.

Broadband: Network connection that can carry multiple signals at once, each on separate channels. Broadband networks can transmit a lot of data, including voice and video, rapidly over long distances.

CD-ROM: Compact Disk-Read Only Memory; a format for storing large amounts of data (e.g., an encyclopedia, complete with photographs and drawings) on compact disks.

Digital: Representing data as discrete *bits*, as opposed to *analog* (see above). For example, CD players are digital: they convert and store sound as bits. Record players, by contrast, are analog devices.

Distance learning: Using video technology to allow students in one location to participate in a class being broadcast from another location.

E-mail: Electronic mail—messages transmitted electronically between computers.

Ethernet: A protocol and set of cabling specifications for local area networks. Ethernet has a transfer rate of 10 megabits per second.

Hard disk: A computer storage medium that is a fixed part of the computer's hardware (specifically, the data storage part of the computer's hard disk drive). As contrasted to *floppy disk*, a portable computer storage medium that can be inserted into or removed from various computers easily and quickly.

Interactive: Referring to programs or applications that respond directly to the user, taking instructions and giving feedback.

Internet: An international computer network that links over ten thousand individual networks and supports millions of users.

ISDN: Integrated Services Digital Network, a worldwide digital transmission network and format that can carry both data and voice over a single cable at speeds of 56 kbps and higher.

Kbps: Kilobits per second, the number of *bits* transmitted every second as measured in multiples of about one thousand (1024) bits per second.

LAN: Local Area Network, a group of computers and related equipment connected locally—usually within a single building—by a communications channel capable of sharing information among several users.

Mbps: Megabits per second, the number of *bits* transmitted every second as measured in multiples of about one million (1,048, 576) bits per second.

Multimedia: Communication that combines text with graphics, sound, animation, full-motion video, etc.—usually in a highly *interactive* way (see above).

Multimedia-capable computer: A computer that is capable of operating *multimedia* applications.

Narrowband: A voice-grade transmission channel capable of transmitting a maximum of 34,000 bits per second. See *bandwidth*.

On-line: Describes any application or information directly accessible on a computer or computer network, such as an "on-line database."

POTS: Plain Old Telephone Service; a POTS line is a standard analog telephone line operating at *narrowband* speeds.

RAM: Random Access Memory—the main system memory in a computer, used for data, applications, and operations.

RBOC: Regional Bell Operating Company, or "Baby Bell."

T-1: A long distance, point-to-point communications channel that transmits 1.5 megabits per second and can carry both voice and data.

T-3: A long distance, point-to-point communications circuit that transmits 44.7 megabits per second and can provide up to 28 T-1 channels. It usually runs over fiber-optic cable.

WAN: Wide Area Network, a long-distance computer network that enables users to share information across large geographical distances (e.g., state to state). A WAN may interconnect a number of *LANs* (see above) at different sites.

Wideband: A transmission channel capable of transmitting more information (as measured by bits per second) than narrowband, but less than broadband.

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Hendrick, Robert. Director of Technology, Carrollton School District, Georgia. Several interviews during May-June 1995.

Moon, Cornelius. Technology Supervisor, Calcasieu Parish, Lake Charles, Louisiana. 8 June 1995.

Moretti, Frank, Assistant Headmaster; Rob McClintock, Director of Institute of Learning Technology at Columbia University and co-director of Dalton Technology Plan; Rachel Packman, Associate Director of Communications; Bob Matsuoka, Associate Director of Information Services and Project Development. The Dalton School, New York. 29 March 1995.

O'Driscoll, Paul. Director, Technology and Information Services, Salem-Keizer Public School District, Oregon. 11-12 May 1995.

Pruitt, Greta. Principal, Los Angeles Unified School District Math, Science, and Technology Magnet School. 8 March 1995.

Reese, Paul. Computer & Technology Coordinator, Community School District Five & Ralph Bunche School, New York. 30 March 1995.

Rescigno, Ronald, Dr., Superintendent; Peter Frank, Teacher, Blackstock Junior High School; Robin Freeman, Principal, Blackstock Junior High School; Deloris Carn, Prinicipal, Green Junior High School; Ed Jones, Principal, Sunkist Elementary School. Hueneme School District, Port Hueneme, California. 31 May 1995.

Weast, Jerry, Dr., Superintendent; Dr. Loretta Changery, Associate Superintendent. Guilford County School District, Greensboro, North Carolina. 19 April 1995.

State and local government

Agrawal, Piyush. Deputy Superintendent, Piscataway School District, New Jersey. 8 June 1995.

Blacktecky, Alan. Vice President, Information Technologies, Microelectronics Center of North Carolina. 19 April 1995.

Crewson, Walker. Director, Office of Telecommunications, Policy Analysis, and Development, New York State Education Department. 10 May 1995.

Elioni, Joe. Director of Instructional Technology, State of New York Department of Education. 7 June 1995.

Johnson, Pamela. Director of Educational Telecommunications, Iowa Public Television. 8 June 1995.

Kim, Kay. Director of Network Support Services, Hawaii Department of Education. 12 May 1995.

Patterson, Jane Smith, Advisor to the Governor for Policy, Budget & Technology, Office of the Governor, State of North Carolina; Richard Kelly, Technical Manager, North Carolina Information Highway; and Rachel Eagles, Manager of Client Relations, State Information Processing Service. 18 April 1995.

Wright, Ron. Education Technology Specialist, Alabama State Department of Education. 9 May 1995.

Federal government

Breeden, Laura, Director of Telecommunications and Information Infrastructure Applications; and Bernadette McGuire-Rivera, Associate Administrator, Office of Telecommunications and Information Applications. National Telecommunications and Information Administration. Washington, D.C., July 1995.

Fitzsimmons, Ed. Special Assistant for Education & Training, Office of Science and Technology Policy, Executive Office of the President. 26 July 1995.

Fulton, Kathleen. Senior Analyst and Project Director, U.S. Congress Office of Technology Assessment. 21 March 1995.

Gips, Don, Deputy Director, Office of Plans and Policy; Karen Kornbluh, Senior Policy Advisor. Federal Communications Commission. 6 April 1995.

Roberts, Linda, Director; Jonathan Hoyt, Special Assistant to the Director, Office of Educational Technology, U.S. Department of Education. 22 March 1995 and subsequent dates.

Young, Peter, Executive Director; Jane Williams, Research Associate. National Commission on Libraries and Information Science. 29 June 1995.

Universities and research institutions

Carlitz, Bob. Professor of Physics, University of Pittsburgh. 7 June 1995.

Cradler, John. Legislative Policy Specialist, Far West Laboratory for Educational Research and Development. 8 June 1995.

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Heaviside, Sheila. Associate Director, Fast Response Survey System, Westat. 14 March 1995.

Kirst, Mike, Professor and Project Director, Consortium for Policy Research in Education, School of Education, Stanford University. 31 July 1995.

McKnight, Lee, Associate Director; Suzanne Chambliss Neil, Associate Director; and Russell Rothstein, Research Assistant. MIT Research Program on Communications Policy, Center for Technology, Policy and Industrial Development. 20 April and 22 August 1995.

Thompson, Hunter. Assistant to the Vice-chancellor, University of North Carolina at Wilmington. 19 April 1995.

Wallace, David. Director, The Sequoyah Group. 20 March 1995.

Associations

Betzler, Mary. Executive Director, Cellular Telecommunications Industry Association Foundation for Wireless Telecommunications. 17 May 1995.

Byer, David, Education Policy Manager; and Susan Kamp, Director, Education Section. Software Publishers Association. 10 May 1995.

Galvin, Jay. Educational Director, National Cable Television Association. May 1995.

Harris, LaDonna. President and Founder, Americans for Indian Opportunity. 16 May 1995.

Kaplan, Deborah. Vice President, World Institute on Disability. May 1995.

Williams, Cheryl. Director, Technology Programs, National School Boards Association. July 1995.

Yentzer, Barbara J., Director, Center for Education Technology; Kenneth Melley, Assistant Executive Director, Centers for Advocacy and Public Affairs; Ronald D. Henderson, Director, Research; and Michael Kahn, Manager, Education Finance and Economics. National Education Association. 14 June 1995.

Not-for-profit organizations

Bastian, Sue. Executive Director, Teaching Matters. 31 March 1995.

Bracey, Bonnie. Co-founder, Online Internet Institute. September 1995.

Krueger, Keith, Managing Director; and Bill Wright, Executive Director. Consortium for School Networking. 20 March 1995.

Decrem, Bart, Executive Director; and Hector Campos, Program Director. Plugged In. 17 May 1995.

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Hawkins, Jan, Executive Director; Margaret Honey, Associate Director; Laura Jeffers and Bob Speilvogel, Senior Research Specialists. Center for Technology in Education. 4 April 1995.

Johnson, Gary. Executive Director, Tech Corps. 7 September 1995.

Saal, Harry. President and CEO, SMART Valley, Palo Alto, California. 1 June 1995.

Welsh, Carol. Program Manager, 21st Century Education Initiative, Joint Venture Silicon Valley Network. 18 September 1995.

Industry

Bosley, John. Associate Director, NYNEX. 9 June 1995.

Bradsher, Monica. Managing Editor, National Geographic Kids Network; and Ray Cooper, Assistant Vice-President of National Geographic Society and Associate Director of Educational Media Division. July 1995.

Burton, Don. Director of Business Development, Disney Education, Disney Interactive. May 1995.

Casados, Benito. Executive Director, Educational Systems, Galaxy Classrooms. 16 May 1995.

Charlton, David. Business Development Manager, Opto-Electronics Group, Corning Incorporated. 25 July 1995.

Cohen, Rhonda. Area Manager, TCI of Contra Costa County and Walnut Creek. Tele-Communications, Inc. 22 May 1995.

Conway, Mark. Manager, Education Industry, Digital Equipment Corporation. March 1995.

De Susa, Tony. Account Executive, LANcity. 19 May 1995.

Garbanati, Linda. Senior Systems Engineer, Bellcore. 1 June 1995.

Gerwe, Kate. Director of Programming, DaVinci Time and Space. March 1995.

Gomez, Eduardo, President and General Manager, KABQ Radio. 23 May 1995.

Horner, Doug, Project Manager; Michael Churton, Project Manager; Mike Goodwin, Applications Engineer; and Nancy Mitchell, Deployment Coordinator. Education First, Pacific Bell. 31 March 1995.

Jones, Lynn. Product Manager, Video and Interactive Information Services, Digital Equipment Corporation. 21 April 1995.

Kandathil, Jacob, Manager, Business Planning & Operations; John Santoro, Marketing Manager. Education Division, Apple Computer. 31 March 1995.

Kerkeslager, Woody. Vice President, Technology and Infrastructure, AT&T. June 1995

Lovette, Jim. Apple Computer. 10 May 1995.

Mageau, Therese. Director of Technology and New Business Development, Scholastic, Inc. 31 March 1995, 12 September 1995.

Morris, Irv. Director, Education Services, Convergent Media. New York, 31 March 1995 and May 1995.

Phillipps, B.G. Manager, Switch Capacity Management. Bell South Telecommunications. May 1995.

Reede, Chris. Major Account Manager. T-line Services. 10 May 1995.

Robins, Dennis. Staff Director, Education Markets, NYNEX. 1 June 1995.

Rosenthal, Ilene. Washington, D.C. representative and General Counsel, The Lightspan Partnership. 14 June 1995.

Tanzer, David. Chief Operating Officer, Channel One Communications. 31 March 1995.

Torrey, Michelle. Inside Sales Manager, RadioLAN, Inc. May 1995.

Wright, Pat. Director of Educational Services, TCI Educational Technologies, 22 May 1995.

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